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Engineering Education

BEING THE

Proceedings of Section E

OF THE

World's Engineering Congress

HELD IN

Chicago, Ill.

July 31, to August 5, 1893

PUBLISHED BY THE

Society for the Promotion of Engineering Education

AS

Volume 1

of their Proceedings

EDITED BY

DeVolson Wood, Ira O. Baker, J. B. Johnson,

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Columbia, Mo.
E. W. STEPHENS, Printer
1894

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1893-4

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CONSTITUTION

of the Society for the

Promotion of Engineering Education.

1. NAME.—This organization shall be called the SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION.

2. MEMBERS.—Members of this society shall be those who occupy, or have occupied, responsible positions in the work of engineering instruction, together with such other persons as may be recommended by the Council.

3. COUNCIL—The Council of this society shall be composed of members from twenty or more engineering schools of the United States and Canada.

4. ELECTIONS.—The name of each candidate for membership shall be proposed in writing to the Council, by two members to whom he is personally known; such names shall be approved by the Council before the vote of the Society is taken. Members of the Council shall be elected in such manner as the Council shall prescribe.

5. FEES AND DUES.—The admission fee shall be three dollars and the annual dues two dollars, payable at the time of the annual meeting. Those in arrears more than one year shall not be entitled to vote nor to receive copies of the proceedings, and such members shall be notified thereof by the secretary one month previous to the annual meeting.

6. OFFICERS.—There shall be a president, two vice-presidents, a secretary, and a treasurer, each to hold office for one year. They shall be chosen by a vote of the members at the annual meeting. Members of the Council only shall be eligible to these offices.

The Council shall constitute a general executive body of the society, pass on proposals for membership, attend to all business of the society, receive and report on propositions for change of rules, and shall have power to fill temporary vacancies in the offices.

7. MEETINGS.—There shall be a regular annual meeting occurring at the time and place of the meetings of the American Association for the Advancement of Science.

8. PUBLICATIONS.—The proceedings of the society, and such papers or abstracts as may be approved by the Council, shall be published as soon as possible after each annual meeting.

9. AMENDMENTS.—These rules may be amended by a two-thirds vote at any regular meeting, after action thereon by the council.

Rules Governing the Council.

In accordance with the constitution, the Council adopted the following rules:

1. This Council shall consist of twenty-one members, one-third of whom shall retire annually.

2. Any member of this society shall be eligible to election to the Council, provided that not more than one member of the council shall be from any one school.

3. Nominations for members of the council shall be in the hands of the secretary on or before June 1, of each year. Members of the Council shall be elected by ballot by the entire membership of the society.

OFFICIAL REPORT

OF THE

MINUTES OF THE PROCEEDINGS

at the Opening Session of the

International Congress of Engineering

Held in the Memorial Art Palace, in the City of Chicago,

During the Week Beginning Monday, July 31, 1893.

The various divisions of the World's Congress of Engineers met in joint session at the Hall of Washington in the Memorial Art Palace, Chicago, Illinois, on Monday, July 31, 1893, at ten o'clock A. M.

Mr. Charles C. Bonney, president of the World's Congress Auxiliary of the World's Columbian Exposition, called the congress to order and delivered an address of welcome.

Mr. Bonney stated that, owing to the unavoidable absence of Mr. E. L. Corthell, chairman of the general committee of the World's Congress Auxiliary on Engineering Congresses, Mr. O. Chanute, first vice-chairman of the committee, would act as presiding officer in his stead.

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Mr. O. Chanute was then introduced by Mr. Bonney, and after referring to a communication from Mr. Corthell dated City of Mexico, July 22nd, stating that on account of continued indisposition and for other reasons it would be impossible for him to be present, delivered a further greeting.

Mr. O. Chanute stated that there were so many countries represented that it was impossible to hear from them all at this session, and that therefore he would call for responses from only five or six of the principal countries, and would first ask for a response from the mother country—Great Britain.

Sir Benjamin Baker, builder of the Forth bridge, was then introduced and responded for Great Britain.

For France, Baron Quimette de Rochemont responded in the French language. His remarks were translated into English by the chairman.

Mr. Chanute then introduced Mr. B. O. Gleim, of Hamburg, the representative of the Associated Engineering Societies of Germany, who responded for Germany.

Mr. Hugo Koestler, chief engineer of the Austrian State Railway, after stating in English that he had the honor to bring the compliments of the Austrian Society of Civil Engineers and also of the Engineers who were sent by the Austrian Government and the Austrian Railroad, responded in German for Austria-Hungary.

Prof. Neiberg, of St. Petersburg, responded for Russia, and Mr. Celso Capacci for Italy.

The chairman then stated that he hoped to hear at greater length at the closing session from the representatives of the various foreign societies represented in the congress.

The chairman of the various divisions were then called upon to respond and addresses were accordingly made as follows:

On behalf of Division A, Civil Engineering, by Mr. William Metcalf, president American Society of Civil Engineers, chairman.

On behalf of Division B, Mechanical Engineering, by Mr. Eckley B. Coxe, president American Society of Mechanical Engineers, chairman.

On behalf of Division C, Mining Engineering, and Division D, Metallurgical Engineering, jointly in charge of the American Institute of Mining Engineers, by Mr. Henry M. Howe, president American Institute of Mining Engineers, chairman.

On behalf of Division E, Engineering Education, by Prof. I. O. Baker, University of Illinois, chairman.

On behalf of Division F, Military Engineering (Major Clifton Comly, chairman of that division, not present) by Lieut. Henry L. Harris, secretary.

On behalf of Division G, Marine and Naval Engineering and Naval Architecture, by Com. George W. Melville, Chief Engineer U. S. Navy, chairman.

The chairman then announced that printed advance copies of the different papers to be read could be had by application to the secretary of divisions A, B, C, D, E, F and G, and that a copy of the volumes of proceedings would be given gratuitously to each society represented and to each foreign government represented, and that such volumes of proceedings could be had by individuals at cost, by application to the secretaries of the various divisions.

An invitation was received and read to visit the United States Coast Survey Steamer Blake, on exhibition at the World's Fair.

The chairman then declared the International Congress of Engineers open.

PROGRAM OF DIVISION E.

MONDAY, JULY 31, 1893.

HALL OF WASHINGTON—10 A. M.

Formal opening of the Congress. General session of all divisions.

HALL 33—11:30 A. M.

Opening address, PROFESSOR IRA O. BAKER, Chairman of University of Illinois.

"Present State of Collegiate Engineering Education."

(a) "Mining Engineering,"* SAMUEL B. CHRISTY, Professor of Mining and Metallurgy, University of California, Berkeley.

(b) "Electrical Engineering,"† H. S. CARHART, Professor of Electrical Engineering, University of Michigan, Ann Arbor.

(c) "Architecture,"† N. CLIFFORD RICKER, Professor of Architecture, University of Illinois, Champaign.

(d) "Mechanical Engineering," the Committee in charge of Division.

(e) "Civil Engineering," the Committee in charge of Division.

"The Ideal Engineering Education," WILLIAM H. BURR, Professor of Engineering, Harvard College, Cambridge, Massachusetts.

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* Presented in joint session of the three divisions of Mining Engineering, Metallurgy and Engineering Education.

†Not presented.

TUESDAY, AUGUST 1st.

HALL 33—10 A. M.

Papers.

"Maximum and Minimum Mathematics Necessary for an Engineer," ARTHUR N. TALBOT, Professor of Applied Mathematics, University of Illinois, Champaign.

"Present Favorable and Unfavorable Tendencies in Engineering Education," PALMER C. RICKETTS, Director Rensselaer Polytechnic Institute, Troy, New York.

"Comparison between American and European Methods of Engineering Education," GEORGE F. SWAIN, Professor of Civil Engineering, Massachusetts Institutes of Technology, Boston.

† "Civil Engineering Education," J. A. L. WADDELL, Kansas City, Missouri.

† "Views of Practicing Engineers as to the Methods and Needs of Engineering Education."

WEDNESDAY, AUGUST 2d.

HALL 33—10 A. M.

Papers.

"Shop and Laboratory Equipment," DR. R. H. THURSTON, Director Sibley College, Cornell University, Ithaca, New York.

"Laboratory of Hydraulics at Massachusetts Institute of Technology," DWIGHT PORTER, Professor of Hydraulic Engineering, Massachusetts Institute of Technology, Boston.

"The Teaching of Graphical Methods in Engineering Colleges and Schools," H. S. HELE-SHAW, Professor of Engineering, University College, Liverpool, England.

"Original Research by Students," R. C. CARPENTER, Professor of Experimental Engineering, Sibley College, Cornell University, Ithaca, New York.

CHARLES D. MARX, Leland Stanford Junior University, Palo Alto, California.

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† Not presented.

THURSDAY, AUGUST 3d.

HALL 33—10 A. M.

Papers.

"Field Equipment and Field Practice," CHARLES D. JAMESON, Professor of Civil Engineering, State University of Iowa, Iowa City.

"Methods of Training Engineering Students in Technical Literary Work," MANSFIELD MERRIMAN, Professor of Civil Engineering, Lehigh University, Bethlehem, Pennsylvania.

"Methods of Studying Current Technical Literature," J. B. JOHNSON, Professor of Civil Engineering, Washington University, St. Louis, Missouri.

"Drawing for Engineering Students," CHARLES S. DENISON, Professor of Drawing, University of Michigan, Ann Arbor.

FRIDAY, AUGUST 4th.

HALL 33—10 A. M.

† General discussion: Number of hours per day, days per week and weeks per year required in college work.

"Vacation Work," ALFRED E. BURTON, Professor of Topographical Engineering, Massachusetts Institute of Technology, Boston.

"Graduation Theses," GAETANO LANZA, Professor of Applied Mechanics, Massachusetts Institute of Technology, Boston.

† General discussion: Degrees conferred.

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† Omitted for lack of time

PROCEEDINGS.

MONDAY, JULY 31, 1893.

10 A. M.

Formal opening of the Congress, General Session of all divisions.

11:30 A. M.

Opening Session of Division E, in Room 33, Art Palace, Professor Ira O. Baker, chairman of the Division Committee, in the chair. In the absence of the secretary (Professor Hoag), Professor C. Frank Allen was elected secretary, *pro tem.*

Adjourned to meet with Mining Engineering Division to listen to the reading of a paper on Mining Engineering Schools, by Professer S. B. Christy.

12:20 P. M.

Division E returned to Room 33 and took up the discussion of Professor Christy's paper.

The authors of the papers on Electrical Engineering and Architecture were not present. The chairman announced that the committee in charge of this division would present, before the opening of the next session, diagrams and tables upon the walls of the assembly room giving data concerning the present state of civil and mechanical education in the United States.

Professor Burr's paper not being ready, it was voted that the printed program be followed and that omitted papers be read after having finished the regular order.

Adjourned at 1:30.

TUESDAY, AUGUST 1, 1893.

10 A. M.

Paper on "Maximum and Minimum Mathematics Necessary for an Engineer," by Professor A. N. Talbot, read. Voted that the discussion of this and the next three papers be postponed until all have been read.

Professor P. C. Ricketts read a paper on "Present Favorable and Unfavorable Tendencies in Engineering," and was followed by Professor Swain on "Comparison between American and European Methods of Engineering Education."

Professor J. A. L. Waddell, not having a written paper asked to have Professor Burr's paper on "The Ideal Engineering Education" occupy the time allotted to himself, which was done.

The four papers were then discussed by Professors Goodman, Bull, Eddy, Robinson, Johnson, Christy, Allen, Wood, Waddell.

Professor S. W. Robinson, president of the Association of Teachers of Mechanical Engineering explained the object and organization of that society, and invited those interested in engineering education to meet his society at 9 A. M. Wednesday morning to consider methods of organization of the engineering teachers.

WEDNESDAY, AUGUST 2, 1893.

10:15 A. M.

Invitation to visit Jackson Park on the Whaleback steamer was presented and accepted.

Dr. R. H. Thurston read his paper on "Shop and Laboratory Equipment," which was discussed by Professors Johnson, Eddy, Jacobus, Spangler, Carpenter, Ripper, and Robinson.

"Teaching of Graphical Methods in Engineering Schools and Colleges," by Professor H. S. Hele-Shaw, Liverpool, England, was read by the author, and discussed by Merriman, Johnson, Eddy, Jocobus. Carpenter, Goodman, Landreth, Spangler, Kneeland, Robinson, Hibbard, Ritter, Humphreys, R. S. Woodward, and Hele-Shaw.

Professor R. C. Carpenter read a paper on "Original Research by Students," and a paper on the same subject prepared by Professor Marx, was read by Professor Hoskins. Both papers were discussed by Professors Jacobus, Spangler, and Carpenter.

An invitation to visit Armour Institute was presented. An invitation by Chief Skiff of the department of Mines, World's Columbian Exposition, to a reception and collation at the Mine's Building, Friday, 8 to 10 p. m., accepted.

THURSDAY, AUGUST 3, 1893.

10:15 A. M.

Professor Dwight Porter presented his paper on "The Laboratory of Hydraulics of the Massachusetts Institute of Technology," which was discussed by Professors Merriman, Goodman, Robinson, Talbot and Porter.

The paper by Professor C. D. Jameson on "Field Equipment and Field Practice," was read by Professor J. B. Johnson and discussed by Professors Munroe, Merriman, Talbot, and Burton.

A paper by Professor Mansfield Merriman on "Methods of Training Engineering Students in Technical Literary Work," was read, and by vote the discussion of it was postponed until after the reading of the next paper. Professor Johnson spoke upon "Methods of Studying Current Technical Literature." The two preceding papers were discussed by Professors Landreth, Johnson, Eddy, Wood, Swain, Lanza, and Talbot.

Professor C. S. Dennison read his paper on "Drawing for Engineering Students," which was discussed by Messrs. Baldwin, Spangler, Dunlap, Lanza, and Spangler.

FRIDAY, AUGUST 4, 1893.

10:15.

Moved and carried that all the regular papers be read before beginning the "General Discussions."

Professor A. E. Burton then read his paper entitled "Vacation Work," which was discussed by

Messrs. Johnson, Humphreys, Merriman, Ricketts, Talbot, and Burton.

The paper on "Graduating Theses," was read by Professor Lanza and discussed by Johnson, Aldrich, Rickets, Lanza, Wood, and Lanza.

Moved and carried to omit the other two topics on the program.

Voted that the publication of the papers presented before this division of the Congress be left in the hands of the divisional committee of the Congress Auxiliary with power to turn them over for publication to an organization of engineering educators if such is effected.

A vote of thanks was extended to the chairman, secretary, the Congress Auxiliary committee, and to the committee of the Associated Engineering Societies for the stenographic report of the proceedings.

Pending this motion, Professor Spangler said that he would like to say that when he came from Pennsylvania to Chicago he had no knowledge that there would be such a Congress, and he personally felt under obligation to the parties who brought about this meeting. He thought that the vote of thanks which had been adopted was very small compensation to these gentlemen who had given such a large amount of time and energy in bringing about these results.

Professor Hele-Shaw said, on behalf of the foreign members, that, although they knew from former experience that they should be well received here, they had no idea that they should obtain so much benefit, that these meetings would be so full of instruction and so extremely interesting. All of them who had come from across the water to this Congress felt that, putting the wonderful show, which is so interesting, out of the question, they should have deemed it worth while to come to this Congress for the sake of meeting so many engineers and professors of engineering, and for the sake of these meetings, and therefore he proposed to second the resolution on behalf of those who came to attend the Congress.

The chairman replied that he scarcely knew how to express his appreciation of the remarks and of the vote that had just been taken. He assured the meeting that he had sought to do what he could to further the purposes of the educational section of the Congress, as in so doing he was but furthering the purposes for which he had given his life, and he was very glad if any one had been helped by this fine opportunity for association, and for listening to the papers of others. Above all, he took pleasure in knowing that this meeting had been the occasion of the organization of an Association of Engineering Teachers.

It was a source of great disappointment to the committee, and more particularly to the chairman, that they were not able to give such notice as was intended and was provided for. It was no fault of any member of the committee that further advertisement of this section of the Engineering Congress was not made. It was a serious fault which need not now be considered, but it had seemed to him that the professors of engineering here gathered together should be congratulated on the fact that without notice they had gathered here from day to day in very considerable numbers when there were other very interesting meetings progressing all about them, and a World's Fair as one of the great attractions, and still there had been a very large attendance, upon which the professors at large should be congratulated. The profit and the interest in this meeting was very largely due to the gentlemen who had prepared papers, and he thought these gentlemen should receive the thanks of all there assembled. It was a very cordial response that the committee met in the solicitation of papers. They had a few declinations because engineering professors are very busy, and some were not able to do what they seemed to be entirely willing to do, and those who had prepared papers had done so out of their vacation time, and that fact should be recognized. The papers will speak for themselves when they are put into type, and for the little part that he had been privileged to do, he had been more than abundantly repaid by the very many acquaintances that he had made here, with friends both on this side and upon the other side of the water.

The section adjourned *sine die.*

C. Frank Allen,
Secretary.

Ira O. Baker,
Chairman.

PAPERS AND DISCUSSIONS
BEFORE DIVISION E,

ON

ENGINEERING EDUCATION.

THE IDEAL ENGINEERING EDUCATION.

By WM. H. BURR,
Professor of Civil Engineering, Columbia College School of Mines, New York.

As no course of professional study can possibly fit any student for a complete and mature professional practice, it is a safe assumption that even "the ideal engineering education" cannot be expected to produce young engineers so mature in the exercise of all their professional functions that nothing is left for the years of subsequent practice to accomplish in the direction of education. This point should be emphasized at the outset, for the reason that many men engaged in practical duties of an engineering nature frequently, and perhaps usually, complain that within their own experience, young engineers almost invariably have failed to possess immediately that grasp of practical detail and well-balanced judgment which gives to the experienced practitioner the almost unconscious power of so perfecting plans and conducting operations as to perfectly control and utilize all indeterminate factors and blend them in proper proportion with the purely physical elements of the problems which lend themselves to exact treatment. It is true that young engineers have not acquired through their education those ripe powers which are the fruits of years of professional practice or of actual experience. The postulates of those very critics are enunciated from a vantage ground of middle life, or even later years, from which a clear view of their own earlier qualifications is quite obscured, either by present activities or by a failure to appreciate either the purposes or the scope of professional education. It is not here maintained that these critics in practice are either many in number or that they give a ruling tone to the consensus of professional opinion as to education in engineering, yet they constitute an existing type, and their strictures merit attention, since they accentuate the consideration of at least some of the principal features which should characterize an ideal engineering education. The fundamental motive of this criticism is not influenced by the fact that education, particularly professional education, creates nothing; that its functions are to draw out, to develop systematically and symmetrically those latent powers with which the individual is endowed, not in ripeness and maturity, but in condition only for growth. This indeed is, or ought to be, the purpose of all education, but it is particularly true of the ideal engineering education or of any other professional education, since the latter requires the exercise of such functions under conditions belonging to the completion of an antecedent training of a more general character. Although the status of both the education of engineers and of their calling is still such that all courses of engineering study in this country are in their earlier portions combinations of arts and technics, yet the distinction is vital. Training in arts is of a liberal character; its purposes is a general cultivation of the individual, and it may be accomplished by certain series of acquisitions in various portions of the broad field of arts; each set of results, characterized by the same degree of excellence, being equally effective. Hence the elective system of studies which has been so widely developed in some of the greatest universities. The purpose of any given course of professional training, on the other hand, is perfectly specific, and the necessary acquisitions are included within the limits of a rather narrow range of subjects more or less closely related and possessing considerable similarity or, at least to some extent, the same motive. In the older learned professions this sequence of a broad and general cultivation prior to, and forming the foundation of, the subsequent professional training, is well defined, and the ultimate nature of the case in engineering is precisely the same as that in law or in medicine. By means of a liberal training, the requisite powers of observation and a sound judgment are more symmetrically developed and far more accurately applied in consequence of truer conceptions of the object on which they are brought to bear, and a correspondingly enhanced power of healthy mental assimilation is acquired. The broad cultivation, it matters little when or where it is obtained, is the only effectual corrective for that narrow and malformed excellence in some some special direction, which, while it is certainly much better than no excellence at all, falls lamentably short of the vigorous and well-rounded product of the ideal education in engineering. The writer unhesitatingly places, therefore, as the first and fundamental requisite in the ideal education of young engineers, *a broad, liberal education in philosophy and arts*, precedent to the purely professional training. It would be well, although not imperative, that the liberal education should be given a trend, in its elective portions, toward the special work in engineering which is to follow. Such considerations might wisely govern that portion of the student's career, but they should govern in a subordinate way only. The main purpose should be such a cultivation of human qualities as will subsequently enable engineers to meet men as well as matter. If there is any one quality which is marked by its absence in the educational and intellectual outfit of engineers at the present time it is that by which, in bearing and in communication, men persuade and control other men in the business of life. It is a high attribute to be able to so direct the great sources of power in nature as to adapt them to the use and convenience of man, but all that power of control is essentially material and utterly barren of results, unless other men or even communities, may be first pursuaded that their "use and convenience" are really to be subserved. No greater error can find lodgment in the minds of engineers than the assumption that this general education is purely disciplinary in character and possesses no direct practical value. It has immediate value of the highest order. At the present time there is no executive position in the whole field of industrial activity, including the vast sphere of railway operations, which is not only open to engineers, but actually demanding precisely the services for which their training should fit them. Again, the duties of the consulting engineer are rapidly extending so as to include the exercise of the most potent influences in the control of enterprises depending, not only upon his scientific knowledge as an engineer, but also on his capacity to convey to his clients correct impressions of the relative values of all the elements which effect their interests, and on which their final action will be based. The complete and satisfactory discharge of such functions cannot, from their very nature, be accomplished on a bare possession of technical knowledge. This is indeed essential, but it is just as essential, and perhaps more so, to know how to use it. The character of many of the questions which come before the engineer for consideration almost compel profound and solitary thought, and thus much of his purely professional activity removes him from all cultivating influences of a forensic or rhetorical nature through which men are most moved. There are, then, few professinal men to whom the broadly cultivating influences of a liberal education are more needful than to the engineer. His early professional practice does not induce any development which can fill the voids of a faulty general education, while his later practice demands what only the liberal training can supply.

For this reason I am very strongly inclined to believe that those engineering schools of the future which are to supply the highest grade of professional instruction will, for the most part, be found connected with our greater universities. Doubtless those of our isolated technical schools which have already attained eminent positions as centers of instruction in engineering will develop to even greater eminence, but the circumstances of the past are materially and rather rapidly changing, and the new conditions require more and more the university environment. The systems of instruction in all grades and kinds of the higher educational work attain to greater efficiency and respond far more readily to the requirements of a wider growth when that work is in close, living contact with all that nurtures it. The perfect professional education is not by its nature a product of isolation, but it is the composite and final result of every true educational influence to which the individual has been subjected. Every such influence is rendered intrinsically more effective, and the receptivity of the individual is largely increased in the university atmosphere. Although originally starting with a somewhat different attitude toward this part of the subject, the writer has for many years been convinced by an extended and active experience, considerably more than half of which has been in the most practical kind of practical work, that the views here expressed cannot be successfully contested. These views have recently found further confirmation in the fact that in Great Britain, where advanced education in engineering science for engineers has, until a comparatively late period, been rather generally regarded as of secondary importance, the university of Oxford has made complete within the past four or five years the list of all the principal universities of the United Kingdom affording courses of study in engineering. It is singular that there should have been any doubt or indifference in regard to the university training for an engineer in a country where one of the earliest systematic courses of civil engineering study was founded in a university, and made famous by the name of Rankine. Nevertheless, that which the professional training of the engineer by its nature requires has spontaneously assumed the form of a demand to which the university best responds, and it is as true for this and every other country as for Great Britain. It may, of course, be said that many of the greatest engineers of the past have attained their eminence in many cases without the aid of any advanced education whatever, and that what has not aided in the attainment of such marked success cannot be imperatively necessary to any degree of success. Now it may be said at once that it is not any part of the purpose of an engineer's training to ascertain how little he may know and yet succeed; nor again, are the exceptional powers of genius, or the still more exceptional aids of favoring conditions of life, available for service in the equipment of the great majority of engineers who are to form the profession of the future. The real answer, however, to such an observation is short and simple. There has been, strictly speaking, no profession of engineering until within the last thirty-five years. The eminent men who are so frequently named as the engineers of the past were truly great constructors, but they cannot be placed in the same class as the professional engineers of the present day. Their chief characteristics were a certain kind of genius for construction, and boldness. The writer yields to no one in honoring their memories, but it cannot be denied that they never could be sure of their results except when they had wasted enough material in one structure to make a duplicate under modern design. Any modern engineer who should undertake to follow their precedents would soon find himself without a clientage. Those precedents make admirable monuments, but the engineer of the present must not direct his practical operations by them, but by economic conditions which are based upon exact scientific treatment of all the elements that can influence the end which he wishes to accomplish; and this brings us to what will here be named as:—

The second fundamental characteristic of the ideal education in engineering, *a thorough training in what may be termed the natural philosophy of engineering, which embraces all that body of mathematical and scientific knowledge constituting the pure theory of engineering operations.* This lies directly at the foundation of the professional engineer's practice. Indeed, this feature of an engineer's educational training is as profoundly practical as it is profoundly theoretical; it involves the rules of practice by which an engineer is to reduce his inevitable errors to a minimum; he cannot avoid them all except by doing nothing. Now, whatever duty an engineer may be called upon to perform in a professional way, whether to design an engine or an electric plant, or to build a bridge, a system of water works, or a railroad, he is inevitably compelled to pursue either the one or the other of two courses. He may blindly

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follow precedents, and do something simply because somebody has done something else more or less like it, adopting the handbook method of construction and thus get a result which may for a time satisfy his clients and enable him to secure his compensation, but which he is utterly unable to defend from criticism and which sooner or later the better equipped engineer must usually be required to remodel or reconstruct, either in whole or in part. Or, on the other hand, he may approach his work with an intelligent appreciation of the principles or laws which govern the physical sequence of the things that he is to control and adapt to the use and convenience of that part of mankind served by his clients or directly by himself. In one case he imitates and in the other he creates. In the former he is defenseless against his own ignorance, while in the latter he is equipped for perfect safety, even though he may occasionly err. I do not underrate the value of experience in completing the education of the engineer; experience is an imperative necessity for every human being, and the engineer forms no exception to the law. In fact, his complete education consists of two parts. The first is that systematic and logical training in so much of the mathematical and physical sciences as is included directly in engineering operations or as may be indirectly required by them, and which collectively constitutes the natural philosophy of engineering, which training is secured only in the professional school; while the second results from the experience of the first few years of the young engineer's practical life, and it consists in attaining a capacity to submit the acquisitions of the first to the operation of common sense and a well trained judgment, and thus make them applicable to the real conditions of professional practice. In the latter, the engineer has to treat precisely of the same things as in the former, but not under the same simple conditions nor with the same accuracy of definition. The determinate characteristics of pure theory transform themselves into the most elusive indetermination. Nevertheless, qualitatively they are still the same, and it is the whole essence of modern engineering practice to so control and adapt the laws and quantitative deductions of the ideal conditions of engineering physics as to make them fit with reasonable accuracy its very varying and complicated conditions. That is the highest art of the engineer. There is nothing beyond it, and anything less is crude and unsatisfactory. It is evident from the very nature of this result that its accomplishment can only follow a thorough scientific training in the professional school. There should, however, be made at this point a very sharp distinction between the abstract scientific training of the student in engineering and the corresponding instruction given to the student in pure physics. These two students are acquiring scientific knowledge for two very different purposes, although many portions of the two fields overlap and indeed are identical in many characteristics. The study of pure science requires a wide range of investigation and a thorough knowledge of the inter-relation of all the departments of physics; this includes exceptional facility in the experimental and analytical treatment of all problems under ideal conditions. The student in engineering should also be given a sound elementary grounding in the main departments of physics, but his advanced physical studies must necessarily be limited by the requirements of his future profession. The selection of subjects and the mode of treatment must be governed by the same motive. Whatever he does, should be adapted to his life work, and so clearly and evidently adapted that he can see and appreciate the purpose of his efforts. His powers of investigation and analysis should be developed into a condition of vigor and facility in those directions along which he is to work. In order to accomplish these objects, without which the probability of his marked professional success is remote, his mathematical training must be of the best. This point cannot be too strongly insisted upon. It matters little that the engineer is seldom required in his practical life to use the pure mathematics for purposes of investigation. He needs them most urgently in his course of study as affording a foundation for his mechanics and for the subsequent analytical treatment of such subjects as the elasticity and the resistance of materials, hydraulics and the general theory of machines, the theory of bridge structures, water and wind motors, thermo-dynamics and the steam engine, electrostatics and electro-dynamics, and every other branch of engineering physics. These are intensely practical applications of pure mathematics, and engineers cannot hope in the future to attain to a high grade of professional success without facility in their use. They illustrate and emphasize the meaning of the statement that the mathematical and physical portions of a course of study in engineering should be so constituted as clearly to show their relationship to subsequent professional work. There is another advantage gained by mathematical training which is less important only than that just stated, namely, mental discipline of a logical character. If mathematics are anything, they are logical, and no student can intelligently and rationally pursue the study without acquiring close logical habits of thought of the greatest value in his subsequent practice. It is precisely this mental discipline which will give value to his professional advice on the comparative merits of various proposed works to accomplish a given end. It trains him to carefully weigh all evidence for and against any proposition, and teaches him to avoid that common and frequently fatal error of assumption of conditions not known to exist. If every engineer should make as thoroughly critical and accurate an examination of all the governing circumstances of every work he undertakes as is required for the correct solution of a mathematical problem, a great many machines that have been constructed either would have been designed very differently or not at all, and at least a few completed structures would be found in other locations than those they occupy. In short, it it difficult to form any rational conception of a course of study in engineering other than that in which a thorough study of mathematics is the main feature of fundamental strength. Without it, study in engineering is degraded to a mere descriptive superficiality of technique. An intimate relation exists between mathematical and physical science and the professional practice of engineering which is most essential to the well-being of the latter. This principle has clearly been recognized in some of the oldest and strongest engineering schools of this country and Europe, but there are some quarters in which it has not been admitted.

The first of the James Forrest lectures before the Institution of Civil Engineers of Great Britain was recently delivered by Dr. William Anderson (superintendent of the Royal Woolwich gun factory) and its prescribed subject was the "Inter-relation of Abstract Science and Engineering." The accomplished lecturer, who is an eminent engineer, deplored the well known fact that the engineering profession of Great Britain has in the past clearly disregarded the scientific elements in the education of young men intending to become engineers. He frankly admitted that continental and American engineers had, by pursuing the other course, gained such material advantages over those of Great Britain that the latter had lost perhaps irretrievable ground. At least he maintained that they could never even hope to recover it except by making an advanced and thorough study of abstract science a prominent and indispensable portion of the educational training of young engineers. He did not admit that there could be any alternative; on the contrary, he based his thesis squarely on the present condition of engineering practice in the United Kingdom, and contended that the results demonstrate the positive necessity of abstract scientific knowledge to the engineer. On the continent, this has always been true of the German polytechnics and the French professional schools in engineering, and largely so of the most advanced engineering schools in this country, yet there is not entire absence of the danger, that in the fierceness of competition for large numbers of students in the greater universities of the United States, a requisite degree of scholarly excellence may be forced to give place to a condition of things more conducive to a greater number of graduates. Another most significant fact is the late change in the prescribed qualifications for the grade of students in the Institution of Civil Engineers, by which a scientific education is now deemed essential where it was heretofore scarcely or indifferently recognized. These are very important facts; they are not the opinions of theorists nor the erratic and irresponsible utterances of impracticable men, but they are the spontaneous expressions of needs born of a radically different system from that of the ideal engineering education, which is not only consistent with the present condition of engineering practice, but imperatively demanded by it. The engineer without that which such an education supplies, works under serious direct and indirect curtailment of his powers, and they are the more serious because by their nature they are scarcely discoverable by the sufferer. It is one of the commonest matters of observation that the uneducated or imperfectly educated man possesses, in general, but crude powers of observation and interpretation, or none at all, of the physical things about him, and he is consequently constantly led into error by the very facts which ought to be his guides. The scientific training of the student in engineering, on the other hand, will give to the engineer a basis for the most acute and accurate powers for the interpretation of his experience which he can by any means acquire. It will give him a strong and healthy mental digestion with which to build up a professional individuality from the whole body of his practical experience, including the dryest and most obstinate portions. Further than this, an extension of the same principle induces a receptivity of impressions from influences a little beyond the immediate physical facts of his practice and in the region of economic and general interests affected by them, so that he becomes fitted to fill a broader professional field. The higher extensions of engineering practice of the present day reach interests so thoroughly and even profoundly scientific in some of their features, and so broad and general in others, that no narrow and merely technical education will meet the requirements of the case, and it becomes rapidly less fitted to do so from year to year. The professional engineer is no longer a man with even marked aptitude for construction only. It has come within his sphere not only to employ and to adapt the principles of engineering design, construction, and operation, but also to so present and enforce his conclusions in relation to their effects on economic interests as to carry conviction to the minds of those who direct the latter, and this implies the cultivation of every power calculated to enlarge and strengthen the relations between an individual and those about him. His abstract operations touch at many points living affairs of the community, and it is one of his highest duties to so govern those operations that the interaction of all related interests may be quickened and made more efficient. The capacity of extending these general relations and of placing himself in close touch with the interests to which they lead is by far the greatest power which the engineer can exert in the legitimate extension of his clientage, and it has the added advantage of being absolutely free from that abhorrent method of loud newspaper advertisement of the quack variety by which a man may truly keep his name everlastingly before the public, but which, after all, gains him but notoriety and not reputation. In any aspect of the subject, therefore, whether in the abstract or in relation to pecuniary compensation, it must be admitted that the education in engineering which both trains a man to be a power among men and equips him with the highest quality of strictly professional preparation is the only education which meets or can meet the requirements of the best engineering practice of the present or of the future.

It is possible that the general principles which have been stated are more forcibly illustrated by the progress of mechanical engineering in the field of the application of steam to industrial purposes, and in electrical engineering, than by such results as civil engineering has thus far afforded. The Pennsylvania railroad, however, is as marked an illustration of the adaptability of engineering principles and practice to a broad engineering enterprise as can be found at the present time. It is not an exaggeration to state that its management has been in the main shaped and directed under influences exerted by the highest grade of engineering education. Further than that, its operating efficiency and economy of maintenance has for many years been maintained at a remarkably high standard by the constant application of what may be called the abstract scientific principles of the natural philosophy of engineering to every detail of those branches of its management, and the wisdom of the procedure is expressed in the dividends. The earliest metallic bridge structures in this country really worthy of the name were the small cast iron or cast and wrought iron spans designed by Squire Whipple. Although the material was in many respects of indifferent character and ill adapted to his purposes, and although many details were exceedingly faulty, the fundamental designs of the structure were scientifically correct, and the efficient service which they continued for many years to render under very much heavier loads than those which they were originally intended to carry shows that they were admirable pieces of engineering work; and they were admirable in spite of the very indifferent material which the iron market then afforded, in consequence only of the sound abstract scientific principles on which their designs were based. Whipple had a perfectly clear conception of the respective functions of chord and web members, which enabled him to design them for the precise duties they were to perform, without the crude and unscientific experimentation with models which preceded the construction of the great tubular structures, and which left their designers (in their apparent ignorance of the relation between chord and web functions) in doubt as to the carrying capacity of their productions, or whether the latter would need adventitious reinforcement, until they were actually completed and tested. From Whipple's time to the present, every material feature in the vast advance of bridge design in this country has been prompted by continually closer scientific study of the principles of that branch of engineering; and such tests of full-sized bridge members as have been made, have simply and only confirmed what theory has already indicated; in no instance have they contradicted the results of abstract scientific study. They have been of inestimable value in supplementing theoretical work by the establishing of quantitative deductions, without which many theoretical conclusions would fail to possess a determinate character. This position is not even weakened by the fact that the ideal conditions of the purely scientific treatment of these engineering questions are transformed into others in the actual case infinitely more complex. Nothing furnishes so clear a realization of the complex circumstances of the actual case as its abstract scientific study, and there is absolutely no way whatever to an intelligent adaptation of experimental results to the complexity of practical conditions, except through the aid of abstract scientific study of the pure theory involved. It requires no extraordinary acquaintance with engineering literature to discover the most convincing evidence of the truth of this proposition. The perennial discovery of new long-column formulæ, the erroneous interpretation of the results of the transverse tests of solid beams, the claims for a hydraulic motor of efficiency greater than unity in the comparatively near past, together with other similar theoretical monstrosities, are not too old to be ignored or forgotten. The general observation to which these instances give force is equally applicable to every field of engineering activity. The application of steam to industrial purposes, more especially in the steam engine, received its most powerful impulse through the scientific work (both analytical and experimental) of Rankine, Clausius, Joule, Hinn, and others; and the conditions of development of steam power in later years have been in strict accordance with the lines marked out by abstract scientific study. There is, however, no department of the natural philosophy of engineering in which the higher branches of physical study have been so essential to the advance of practical engineering work as in that of electricity and magnetism. Indeed, it may be said that there could be no electrical engineering without the most advanced mathematical and physical study in electrostatics and electro-dynamics. It is within the personal knowledge of the writer that, during the past year, two among the largest in this country of what may be called electrical engineering companies have applied to at least one engineering school for a number of electrical engineers equipped with a mathematical and physical training materially beyond that afforded by any four-years' course of study now established in this country, and that equipment was made an indispensable condition for the offer of the unusually large salaries which accompanied the request. There are portions of the field of electrical engineering in which a most profound theoretical knowledge of electricity and magnetism is quite necessary to a competent discharge of the practical duties involved. If it were necessary to add force to what has already been said, mention could be made of the contributions to practical work which have so frequently been rendered by Lord Kelvin, and made possible only by his incomparably profound theoretical knowledge. The arguments for the second essential of the ideal engineering education may rest here, with the general statement that it consists of a most thorough training in mathematics and physics, but adapted in its entire matter and method to the subsequent engineering practice.

One of the most important considerations in connection with the educational training of an engineer is that of the introduction of actual engineering operations, as far as practicable, into the course of study. In this is not included the experimental portion of the instruction in the physical sciences, but to workshop and laboratory practice, instrumental and other field work involved in railway, geodetic, and other surveying operations, the actual design of engineering works, including specifications and estimates, visits of inspection and observation to works in process of construction, as well as to those completed and in use or in operation, and office practice and organization in its varied character and manifold functions. It is at once clear that these classes of work should be included in some degree, and that they should be required, in so far as is consistent with the special field of practice elected by the student. In civil engineering he may, without essential prejudice, omit all workshop practice, although he is clearly better off with an acquaintance with its elements; but he needs and must have laboratory practice in the testing of materials and in such hydraulic operations as lend themselves to that mode of treatment. It is again imperative that he have thorough drill in instrumental and other field work involved in all surveying operations. This is the more important for the reason that it forms a class of duties which it is very probable he will be required to perform at the beginning of his practice, and which, after a few years, in the natural order of things, he will lay aside for others more advanced. The mechanical and electrical engineers, on the other hand, require thorough courses in both workshop and laboratory practice, but they should omit the courses in instrumental work and field operations of surveying. The mining engineer again needs the latter and the laboratory practice, but he may well take the elements only of workshop practice. All students in engineering require as much time devoted to specifications, designs, and estimates; trips of inspection; and to office practice and organization in their respective applications to each speciality as a proper consideration of other essentials will permit. All these are generalities, every one will probably admit, but there is room for great diversity of opinion in reference to the weight or relative importance to be attached to each division of this part of the educational work as compared with others of the same course, and in reference to its position in time within the possible assignable limits. In the consideration of the relative weight or importance of these divisions, it should be observed with emphasis, and borne in mind with the greatest care, that no education in engineering, ideal or otherwise, ever has made a practitioner or ever will, but the best education is that which will prepare the average young man possessing the proper natural endowments to rise in practice to the highest professional plane. It can neither force into him what nature has failed to bestow nor can it equip him with what experience only, which is second nature, can supply; the latter is just as impossible as the former. That being the case, it is clearly the function of the technical or professional school to give him all that fundamental scholarly training in principles which practical experience cannot supply; this is the chief end to be attained in the educational life of the young engineer, for it is his last opportunity to secure it. The urgent demands upon the time and efforts of the young practitioner leave little or no opportunity and less inclination for study, and it is almost certain that deficiencies in the field of study will never be remedied in active life. Any defect in the purely practical part of his education can, at the most, but slightly hamper him at the very beginning of his career, and is soon remedied in the natural order of his experience, while, at the best, those same practical parts of his educational training can be but imperfectly taught prior to his actual contact with the things themselves. Practical impressions received under the unreal conditions of instruction may indeed be more or less sharp and complete, and correspondingly valuable, but any one who assumes to successfully substitute them for the effects of real practice will disappoint others, even if he does not disappoint himself. Indeed, misdirected efforts of this character can scarcely be saved from miscarriage; there will be certain failure to produce a ready-made practitioner and the strongest probability of generating a sort of "wind-fall" young engineer, the scope of whose usefulness and ambition will be confined to a callow excellence in the clerical or office technique, which it is true, brings quick employment after graduation, and just as slow ultimate promotion. Those efforts form a sort of forcing system, which seems prematurely to exhaust or destroy essentially all that power of further growth or development that proceeds naturally, albeit slowly, from a more scholarly preparation followed by a properly balanced and well-rounded practice. These considerations indicate in general a place for the purely practical matters in the curriculum of the professional school supplementary to, and not co-ordinate with, what may be designated as the rational part; not supplementary in point of time, but in point of relative importance or weight. They are absolutely essential to an efficient course of study in engineering, but in estimating their relative weights in the curriculum, they must take places subordinate to the study of principles. The assignment of time and effort should be such, therefore, as to accomplish the study of principles in the most thorough manner, and the accomplishment of the purely practical work should be made consistent with that end. It should not be the aim to perfect students in that craft skill which they will in general be called upon to exercise at most but sparingly. Their functions as engineers will require of them, in the main, a close familiarity with the methods of mechanical performance, but not with the performance itself. The writer does not mean to assert that the young engineer will not frequently, at the beginning of his practice, be required to make the craftsman's experience a part of his own; he probably will, and often should do so, and portions of his education should fit him for such duties; but that is not the ultimate end or aim of the course of study indicated by the curriculum, it is far above and beyond that. *The time and attention given to those mechanical or routine portions of the course of study in engineering, which may be termed the purely practical parts, should be so applied as to thoroughly acquaint the student with methods, and only so much craft-skill in them is requisite as is necessary to that end.* This general principle, which the writer regards as the third essential characteristic of the ideal engineering education, must be applied to each specialty in engineering consistently with its chief purposes. The mechanical engineering student must take a comparatively large amount of workshop practice, but it must be for the training of a mechanical engineer and not for the purpose of attaining the skill of a mechanic.

The student in civil engineering must acquire a high order of facility in the use of surveying instruments, but it must be adapted to his career as an engineer and not as a surveyor; and essentially the same observation may be applied to the instrumental work of the mining engineer. Indeed, the principle is perfectly general, and may be applied to each division of purely practical work in each specialty. The student should attain to that degree of excellence which will enable him at the end of his course of study to make a fair and reasonable connection with the beginnings of his professional career: the professional school cannot qualify him to do more, and he should not be content to do less. There is, again, a possible range in opinion as to the proper place in time for the introduction of these practical or routine matters. They may either precede, or follow, or be concurrent with, the abstract scientific studies to which they are related more or less closely. A careful consideration of the subjects involved will doubtless lead to the conclusion that all these relative positions must be employed. Familiarity with the physical characteristics and uses of tools, machines, simple mechanical processes, instruments, and apparatus cannot be acquired too soon. For this reason, workshop practice should be commenced at the beginning of the course of study, and it should be continued without break, if possible, until the end of the period allotted to it. It would seem that a reasonable number of hours per week will permit this part of any course in mechanical or electrical engineering, if pursued continuously, to be completed within one and one half to two years. If civil or mining engineering students should elect any work of this character, a half of that period, at most, will be sufficient for their purposes. This disposition of time for the purely mechanical or craft part of the student's work will give him a very appropriate and efficient preparation for the extension of the advanced branches of engineering physics into the fields of testing and research, which must of necessity be the work of the latter part of the course of study. The skill in mechanical manipulation requisite for the best quality of such advanced laboratory work as the testing and rating of steam engines and boilers, hydraulic motors, and other prime movers, as well as dynamos and other electric motors, the investigation of methods and devices for the transmission of energy, and for all other similar work will thus be acquired in logical priority to the time of the students' need. These portions will either be concurrent with or follow their analytical or theoretical treatment, as the nature of their various details may make advisable. The same order of procedure should be followed in the more elementary laboratory work of the physical testing of materials and hydraulic gauging, so far as the latter can be treated without field work, little or none of these divisions of the student's operations should precede the rational treatment. While it is undoubtedly true that there are some features of illustrative experimental work which are quite independent of the abstract principles involved, it is just as true that it is impossible to completely and accurately interpret them without a knowledge of those principles, and there are very few cases indeed where the study of the latter should not at least be concurrent with the experiment, and it should usually be precedent.

All field work of surveying and other geodetic operations, the gauging of rivers and canals, visits of inspection and for the purpose of reports, all of which involve the application of principles in the performance of specific duties, must necessarily be preceded by a thorough study of those principles, and by the acquisition of some degree of facility in their application, else the beneficial effects of such exercises will be seriously impaired. There is always more or less danger that engineering clinics, as the inspection of works in progress or operation under the supervision of instructors may be called, may degenerate into mere junketing expeditions. They may be made of distinct value, if the student really performs the work of an engineer, but not otherwise, and in order to accomplish that end he must have at least a material amount of engineering preparation. There can be no doubt of the benefit to be derived from making reports on works inspected independently by the student, beginning at as early a point in his course of study as will enable him to inspect and report upon engineering works or operations with intelligence, and continuing them at reasonable intervals until graduation. He will thus be encouraged to cultivate habits of close observation and the power to form conclusions, which will be of great value to him in his subsequent career.

In discussing these matters of laboratory and field work, such topics as the study of chemistry, physics, geology, mineralogy, metallurgy and assaying have not been mentioned, although they should most certainly be included in the appropriate courses of engineering training. There can be no question about the efficiency of the approved methods of instruction in those subjects pursued in both the universities and advanced technical schools of the present day. The rational, experimental, and field studies are so distributed and executed as to leave little or nothing more to be desired, or to be gained by discussion. It may only be observed in passing that those subjects serve very important ends in the ideal engineering education, and that they must be found occupying essential places in it.

The completion of designs and estimates and the consideration of the specifications which should govern them form a most important division of advanced instruction in engineering, which should invariably follow the rational study of the abstract principles involved. No design of any structure, machine, or process, can be developed on the ideal lines of pure theory, but the necessary adjustment of theoretical results to the complex conditions under which the object of the design is to perform its duty, can best be made and, indeed, can only be rationally made, through an accurate knowledge of the main principles involved. It is indispensable, therefore, that the closest possible acquaintance with those principles should be cultivated prior to that use of them which the engineer must make in the complete design of his works. These designs should be elaborated, as far as possible, with the same careful regard to detail as would be required in the actual execution of the work. The complete estimates of the various classes of material can then be made by precisely the same methods employed in engineering offices, and on those estimates of quantities should be based the estimates of cost. There is reached at this point a portion of educational work which is most difficult to manage in a satisfactory manner. Indeed, it is probable that a perfectly satisfactory result cannot be attained, but it is at least possible to so present to the student the elements of the process of estimating costs that his earliest practical experience will give him complete control of the subject.

He should be made to understand that there are economic as well as mechanical principles, and that a smaller quantity of material with a larger amount of labor put upon it may considerably exceed in cost a larger quantity of material on which less labor has been expended. The reduction of shop costs through extension of facilities for handling material, and the improvement of processes can be impressed upon his mind in such a way as to prompt him to pursue intelligently in his subsequent practice every effort to secure further advantages in the same direction. Such a presentation of the elements of cost of work, including cost of material, labor, handling, freight, erection, plant, tool rent, office cost, and other similar charges which it is perfectly feasible to put before him in a clear and forcible manner, will give a quality to his realization of the practical nature of engineering work which it is impossible for him to secure in any other way. It is quite within the possibilities of a course of study in engineering to convey to the student healthy and well-balanced ideas as to the influences which will affect the cost of his work, and as to the elements on which the complete cost is to be based, and no school of engineering should be considered as satisfactorily discharging its responsibilities unless it accomplishes that end.

The efficient organization of engineering offices and that of forces and plants for the execution of specific engineering works, as well as the administration of large interests involving engineering operations, such as railways and public works, are all matters which should, if possible, be presented to the student, but in ways that are appropriate to their various characters and consistent with the amount of time and effort which must be bestowed on those other subjects which are fundamentally essential to the course of study. While it is desirable that the student should be brought in touch with these matters, so that he may know that they exist, and, at least approximately, what they are, they are spoken of here thus guardedly because they are not absolutely essential. He can, at best, but derive general impressions at long range, which will have to be materially corrected and developed in their full detail in his practical career; and it is neither necessary nor wise that any considerable portion of his time should be devoted to these administrative features of his later practice, which do not directly affect his immediate professional duties. These observations are not intended to be applicable to post-graduate studies in engineering, which constitute a field of work for the student in which an extended study of organization and administration can most profitably be made.

The method of instruction to be pursued in the school which affords the ideal education in engineering, must be of such a character as to yield the best results with the least amount of unproductive labor to the student, and at the same time train him in the ways of vigorous and independent thought. Dry and lifeless text book recitation work yields by itself little enough that is desirable, while the pure lecture method is equally unsatisfactory. The one is uninteresting routine and utterly ill adapted to the development of mental fertility and strength, while the other involves a mass of misdirected labor on the part of the lecturer, which, without supplementary exercises, leaves the student to shift for himself, without producing much of any result. The main purpose is to convey instruction, and it should be done in such a way as to induce the student to do his own thinking. No instructor can justify himself in merely puzzling the student with grotesque problems, or in harrassing him with abnormal difficulties, but on the other hand the student should be made constantly to feel himself a working part of the system, and that he cannot, without serious loss to himself, take a mere passive part. Unsupplemented lecturing on engineering subjects will not do this, although a very considerable amount of lecture work must be done. The fundamental groundwork of principles with the attendant analytical work and the usual or common applications can most advantageously be put into the hands of the student, either in the shape of a reference or text book or prepared notes, so that the ground to be covered by the lecturer may be carefully worked over by him prior to the lecture hour. The lecturer then need elaborate only the obscure or difficult portions of the subject matter and the applications to living engineering questions in this manner. The student will be induced by reasonable and natural methods to acquire a degree of self-reliance and strength in approaching new problems that will be of inestimable value to him in his engineering practice. This should be the prelude to a close questioning on the entire ground covered by the lecture and the text. There should also be ample opportunity for explanations that may be desired by the students. In fact, a considerable portion of the lectures should be largely of the nature of conferences, so that independence of thought and a keen interest in the subject may be cultivated. A generous amount of work on problems resembling as closely as possible those arising in practice, together with full demonstrations of principles, should be constantly interspersed with the other work of the course. In these problems and demonstrations, the student should be required to defend his demonstrations against criticism. He should be trained to state and defend his views and demonstrations in a concise, clear, and forcible manner, and the attainment of that important end will require all the exercises of this character that any curriculum can afford. To the writer's mind, this matter of the best method of instruction is beset with many various difficulties, some of which can only best be solved in view of the personal qualifications of the instructor. It is a question that has at best given him years of most serious thought, both in the lecture room and in active practice, and both these plans of experience have led him by slow stages to believe that its best solution will be found consistent with the general principles above stated; but he also believes that in the application of those principles the largest liberty for the competent instructor in individual choice and action is most essential.

Such the writer deems to be the requisite features and the main characteristics of the course of study which will enable those who pursue it to acquire the "Ideal Engineering Education." There are then to be grouped along the main lines such a selection and number of subjects as each special field of engineering activity may require, so that each course of study may be completed in all its details. It may be and probably will be objected that this "ideal" is too ideal. But such an objection is groundless; the "ideal" is already too nearly accomplished. Again, aside from such considerations, it is well to remember that that which is not the object of effort is never attained.

REQUIREMENTS IN MATHEMATICS FOR ENGINEERING EDUCATION.

By ARTHUR N. TALBOT,
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Sixteen years ago the author of an engineers' pocket-book stated in its preface that, having long since forgotten the little higher mathematics he once knew, he could not read the profound language of Rankine, Mosely and Weisbach, and that their books are beyond the reach of all but a few engineers, adding that they are but little more than striking instances of how completely the most simple facts may be buried out of sight under heaps of mathematical rubbish. The late editions of this valuable pocket-book have been so thoroughly remodeled that its present arrangement is sufficient refutation of the implication that mathematics is useless for an engineer. Recent engineering text-books show the transformation from the two extremes of Rankine and Trautwine to the present ideas of useful engineering mathematics. It is to this present condition of the place and amount of mathematics in the education of the engineer that your attention is invited.

In order better to consider this relation, it may be well to state the commonly recognized aims and objects of the education of the engineer. These perhaps may be summed up under three heads: *First.* General development. *Second.* The acquirement in part of the methods, knowledge, habits and processes of routine engineering works; in other words, the learning of the trade element. *Third.* The cultivation of the habits, methods, and spirit of observation, investigation, design, and construction, which may be called professional training.

Technical education has become a recognized pre-requisite to the proper practice of the engineering profession. While in the past so many of our ablest and most distinguished engineers have succeeded without this training, and in the future others having natures peculiarily fitted for the work and having secured a discipline not found in the schools, will succeed, yet present conditions are such that the man without this preparation is sadly handicapped, and this preparation is so necessary that it may be said to be a pre-requisite.

The value of an engineering education in the development of a youth is usually recognized. The discipline of the mind, the unfolding of the powers, the transformation from a boy to a man, is well accomplished by a technological course.

The trade-school element has not received much support from educators, but this kind of training has been demanded by many engineers. While the writer is not an advocate of "practical" education in the common acceptation of the term, and believes that the engineers who demand this do not properly appreciate the advantage of potentiality of growth, yet he believes that a working knowledge of engineering details and methods may be wisely included in the instruction with no loss in discipline and development, and that it is due to employer and young graduate that a sufficient amount of this training be given to enable the latter to be of service from the start. While the first years of work must be an apprenticeship, the beginning must be too low down.

But, after all, the third object in an engineering education is the most important,—the special development, the cultivation of the spirit of investigation, invention, design, and construction, and the consideration of projects in a business-like and successful way. It should be the aim of schools of technology to arrange the curriculum and to carry on the instruction so that all these objects will be attained in such a proportion and with such an economy of time that the young engineer may advance farthest in his professional career in his first ten or twenty years.

What part, then, does mathematics have in these ideals? What subjects should be included and what length of time should be given in the instruction?

Mathematics has usually been considered to have a valuable disciplinary power. Judging from the results attained in the average student as ordinarily taught, it is probable that this value has been overestimated by educators.

The necessity for proper training in the use of mathematics as a part of the engineer's practice has not, it seems, been generally appreciated. The graduate should have such a knowledge and mastery of the elements and their use as to be a rapid and accurate computer, thouroughly trustworthy in all ordinary computations and operations. This his employer has a right to demand at the start, though it is probable that this condition is not usually realized.

In the field of the higher professional work, the mathematical training is of inestimable value. The language of mathematics best expresses methods and results; its methods are short-cuts in applied science, labor-saving appliances in demonstration and design. The time was when the use of mathematics by the engineer was deprecated, and the college graduate was expected to forget all he knew upon taking up practical affairs, but now that these branches are taught and used as tools, they become indispensible in the training.

There is a further function as a pre-requisite for the proper presentation in the school of professional subjects whose treatment involves mathematical processes. In many cases, the use of mathematical terms and methods learned in these preliminary subjects, allows a much more rapid treatment, and in many studies they are essential to proper presentation, so that the mathematical training becomes an economical necessity. It is unnecessary to advance proof of this in a gathering of engineering instructors.

On the other hand, a prolonged study of the higher mathematics may be detrimental to the engineer's success. It may misdirect and misappropriate his efforts, and by fixing his mind on exact and theoretical conceptions, decrease his ability and distract his attention for judging indefinite data and from applying methods to every-day problems. For this reason and because so many other subjects claim attention, the amount of time given to mathematics has been somewhat reduced in engineering courses.

It may be a question, then, as to what branches should be taught, and how extensive the training in mathematics should be. A consideration of the amount of pure mathematics given in the technological schools of the country will be of value. In Table I, below, the amount of time given to pure mathematics in twelve institutions, all having distinctively engineering courses of some reputation, with methods of instruction somewhat known to the writer, is shown.

TABLE I.

Data showing relation between time given to pure mathematics and that devoted to the entire course in twelve engineering schools:

INSTITUTION.	Course.	Admission Requirements.	Mathematics in Course.	Total Number of Exercises.	Total in Mathematics.	Per Cent. in Mathematics.	Per Cent. in Calculus.
Mass. Inst. Tech.	C. E. M. E.	1, 2, 3, *	4, 5, 6, 7, 8, 9, *	2380	260	10.9	3.6
Cornell University	C. E. M. E.	1, 2, 3, 4,	5, 6, 7, 8, 9,	2328	290	12.5	5.2
Lehigh University	C. E. M. E.	1, 2, 3,	4, 5, 6, 7, 8, 9,	2454	324	13.1	4.1
Worcester P. Inst.	C. E. M. E.	1, 2, 3,	4, 5, 6, 7, 8, 9,	2920	356	12.2	3.3
University of Michigan	C. E. M. E.	2, 3, 4, 5,	7, 8, 9,	2125	285	13.4	8.0
University of Illinois	C. E. M. E.	1, 2, 3, 4,	5, 6, 7, 8, 9,	2556	360	14.1	6.1
Univerity of Wisconsin	C. E. M. E.	1, 2, 3, 4,	5, 6, 7, 8, 9,	3008	360	12.0	4.6
University of Minnesota	C. E. M. E.	2, 3, 4,	5, 6, 7, 8, 9,	2844	300	10.5	4.2
Purdue University	C. E. M. E.	1, 2,	3, 4, 5, 6, 7, 8, 9,	3000	472	15.7	3.8
University of California	C. E.	1, 2, 3,	4, 5, 7, 8, 9,	2339	352	15.0	3.2
University of California	M. E.	1, 2, 3,	4, 5, 7, 8, 9, 10, 11,	2339	501	21.1	3.2
Stanford Junior University	C. E. M. E.	2, 3,	4, 5, 6, 7, 8, 9,	2040	408	20.0	5.0
Washington University	C. E. M. E.	2, 3, 4,	5, 6, 7, 8, 9,	2807	337	11.8	5.1

* 1. Arithmetic. 2. Algebra. 3. Plane Geometry. 4. Solid Geometry. 5. Plane Trigonometry. 6. Sperical Trigonometry. 7. Advanced Algebra. 8. Analytical Geometry. 9. Calculus. 10. Least Squares. 11. Differential Equations.

It has not been feasible to consider all engineering schools, nor even all of the best, and several of the highest rank have been excluded because of a lack of knowledge of the time given to various subjects. The mathematical training in others does not vary far from those given in the table. Moreover, the table may not be strictly accurate, for the methods of counting and valuing time and the variety of methods of instruction make strict accuracy impossible. However, it is believed that the table is fairly representative of the relation of pure mathematics to the course of instruction in American engineering schools.

The investigation has included courses in civil engineering and mechanical engineering. The course in electrical engineering would show about the same requirements with, perhaps, a wider range of mathematics for work in advanced physics. The courses in mining engineering and in architecture would not vary far from those noted. Only the regular instruction in mathematics will be considered, since the amount given in connection with the technical instruction is so related to other instruction as to make accurate determination impossible.

The instruction in mathematics has been expressed as a percentage of the total number of exercises of the course. By this method much of the difference in value given to each exercise or recitation has been eliminated, and by means of it a fairer comparison may be made.

It will be seen by the table that there is a substantial agreement in the branches included, either as required for admission or as required in the course. These subjects are: arithmetic, algebra through quadratics, plane and solid geometry generally required for admission, and plane and spherical trigonometry, analytical geometry and calculus taken in the course. Descriptive geometry is so interwoven with drawing and other work that its consideration may be omitted. Analytical mechanics has been considered as applied mathematics, and is also omitted.

A glance at this table shows that four do not require an examination in arithmetic. Why this is omitted is not clear. A thorough examination in arithmetic should be given, for it is perhaps the most important branch to the engineer, both on account of its every-day usefulness and by reason of the bearing of its principles on later subjects. The writer's experience is that its teaching is not well done, and that the average student is lamentably deficient. I may add that the old-time mental arithmetic is very valuable for every engineer.

In all these schools algebra through quadratics is required for admission, and one adds that advanced algebra will be required after 1894. All but one require plane geometry, but seven do not require solid geometry. Two of these will after this year. One school requires plane trigonometry, and another will require plane and solid trigonometry and advanced algebra after this year. The condition of high schools throughout the country makes it both feasible and desirable to include all of geometry in the admission requirements. Whether it is best to include trigonometry, unless the school is fed principally from a preparatory school of its own, is not so clear. The drill obtained in classes in high schools, where so few will appreciate the value of trigonometry, is likely to be below the necessary standard, and such a course should be supplemented in the engineering school with a thorough review and a drill in computations and use of tables. The main object, of course, in requiring this subject for admission is to permit the completion of mathematics early in the course, and thus allow the allied subjects to be considered in the earlier years.

Two schools do not require spherical trigonometry, a commendable omission, perhaps, if sufficient drill in plane trigonometry be given.

In addition to the subjects mentioned for the regular curriculum, one school includes differential equations and the method of least squares. The former is of especial value to students in advanced physics, but it is doubtful whether the average engineering student will not be sufficiently prepared without it. The latter is usually given in some form or other in geodesy or other subjects involving the value of observations and averages.

The amount of time devoted to pure mathematics by these schools is nearly the same. With the exception of two schools, the difference between the mean, 13.7 per cent. of the entire course, and 10.5 per cent. on one side and 15.7 per cent. on the other, is not great, when the possible differences in method of counting are considered. Even in the time devoted to calculus, there is substantial unanimity. The consensus of opinion seems to be that arithmetic, algebra, geometry, trigonometry, analytical geometry, and calculus are essential to the economical training of the engineering student, and that 11 to 14 per cent. of the student's time should be given to these subjects. This unanimity in time and subject-matter may not mean a uniformity in methods and thoroughness of teaching.

Instructors generally will agree that all these subjects are economically necessary in the instruction of the engineering student and that the time spent in this training is not extravagant. It would even seem out of place to enter a discussion on this topic. Engineers, however, sometimes object to the calculus, and statements are made that this branch is never used in practice. Even if it had no value to the practicing engineer, its economic value in the presentation of other subjects would cause its retention. A value of mathematical training lies in the gain in quickness and clearness of conceptions, in briefness and accuracy of language in description and explanation. The gain in time and comprehension in other subjects is little understood by these critics. Who would attempt to teach resistance of materials and thermodynamics without it? He would find it an economy of time to teach the calculus first. Besides, calculus is something more than differentiation and integration. The conceptions of rates of change, of the relation of the change of one variable to that of another, of maxima and minima, and of summation are so fundamental to most engineering investigations that it would be folly to attempt such a consideration without a thorough training in this line. Engineers do use the methods and conceptions of the calculus, generally in an indirect way, although they may not realize it, and, thus they fail to appreciate its educational value.

However, there are criticisms made on the results obtained in mathematical training, criticisms that are heard from engineers and instructors. Students do not have that command of mathematical methods, nor that comprehension of the processes, nor that working knowledge of the details, which may be rightfully expected and which is necessary for its use as a convenient tool. The discipline acquired is far less than it is generally asserted to be. The aim of the student is too often the acquirement of only enough of the subject to pass the examination.

Where then, lies the difficulty, if there be one? It does not lie in the selection of the branches taught, nor in the time given to their treatment. The writer is quite reluctant to offer any suggestion for improvement, since the circumstances surrounding the teaching of mathematics are so diverse, but he will suggest a few items which may or may not be considered applicable to the present condition of mathematical teaching.

"Not how much, but how well" should be the precept continually before the instructor. Teach the elements well. Omit much of the complex portions of the subject, or leave it for an advanced course. Don't attempt to cover too much ground. The new concepts require time for comprehension, and the student who is well drilled in the elements will readily take up more complex problems when necessity requires. It is far better for him to master the rudiments and use them as readily as he uses the operations of multiplication and division than to follow through long demonstrations whose meaning he barely comprehends and whose processes are repeated probably through a feat of memory. In general, then, cut out all parts which may be omitted without seriously affecting the succeeding subjects. Then drill the students thoroughly, giving as much individual instruction as possible. It is only persistent, repeated drilling and practice that gives the average student a fair working knowledge of mathematics.

Illustration and application of the principles should be made in every possible way. A dry principle or an abstract statement must have life and reality given it. The bare demonstration may be meaningless without an appreciation of its use. Something tangible must be given before a new concept is comprehended. Success in this direction depends upon the personality of the instructor.

Avoid confining the training to exact and purely theoretical conditions. Let the student see that he may have very indefinite data. Require him to discriminate in the choice of data. Give problems rather than examples—and engineering problems as far as possible. Correct these and grade them, so the student may know how bad his mistakes are and where his methods may be improved. There is much drudgery in this for the instructor, but it is the only way to good results.

Teach the consideration of accuracy as a relative matter. Let the effect upon the result of an error in the work or in the conditions be determined. Give short methods, teach quickness and correctness in operations, and make a trustworthy computer.

But the difficulties do not lie wholly in the instruction; the fault lies largely in the student himself. If only the dreaded tradition about mathematics could be overcome, the remainder of the task would be easier. Get out of the student's mind the idea of a bugbear and let him see its importance and usefulness. The elements of these branches and their use are not difficult to acquire.

But the teaching of mathematics must go beyond its first presentation. The professor of pure mathematics must not be charged with the whole responsibility. The average student may forget the best training and declare that he never heard of some precept which has been fairly hammered into him. It is the privilege and duty of the instructor in many of the later subjects in a technological course to supplement and strengthen the student's mathematical equipment. The application to the varied technical subjects and the wide range of field and laboratory work gives ample opportunity for this, and repeated references should be made and drill given in mathematical matters previously treated. It is a mistake to assume that since the student has passed his previous examination, no further study of the subject need be made, and the various instructors should feel the responsibility. The writer's observation indicates that the value of this training is quite generally felt and and that good results are shown.

The teaching of mathematics bears so important a part in the training of the engineer that it should be carefully discussed. It seems not to have kept pace with the improvement in technological education. The text-books generally used have not been written with the engineering student in mind. Many of the teachers of mathematics are not engineers—although engineering graduates. But they are usually workers, and their aid has been invaluable in the training of that grand body of young men who are such an honor to our engineering schools and to the engineering profession.

PRESENT FAVORABLE AND UNFAVORABLE TENDENCIES IN ENGINEERING EDUCATION.

By PALMER C. RICKETTS,
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The number of topics into which the general subject of engineering education has been divided for purposes of discussion at this conference necessarily restricts each paper and confines it within narrow limits. A general treatment of the subject to be here considered would permit, and perhaps demand, a careful historical review of the development of the methods of education of the engineer in this and other countries. Again, an enunciation of the writer's idea of the ideal engineering education and a comparison with the methods at present in vogue would be a rational method of treatment of the special heading to which he is confined. But since both the historical review and the ideal education are special topics for which provision is elsewhere made, it would not be proper to develop the subject from either of these standpoints. In fact the general scheme of the conference and the method of sub-division wisely provide that the matter presented should be of the nature of concise opinions within narrow prescribed limits, rather than general papers in which repetitions would naturally often be found.

It is not necessary here to prove the wide acknowledgment of the value of a technical training, as well for persons desiring to prepare themselves for business pursuits as for those intending to confine themselves strictly to professional work. Nor are we called upon to discuss the relative values of a classical and of a scientific education as a preparation for a business life. The youngest of us here remembers how many of the academic schools were unwillingly forced to add scientific departments in compliance with public demand and that it took years for some of them to look upon these additions as other than unwelcome though necessary attachments.

It is not the want of appreciation of the value of scientific knowledge but the admission of its usefulness which brings to our consideration an unfavorable tendency in engineering education. Some universities and colleges throughout the country are adding engineering courses without making proper provision for their maintenance. This arises, on the part of the authorities, partly from ignorance of what constitutes an engineering school, and partly from a desire to increase the number of their students without having sufficient capital to provide properly for their instruction. With the "university" bee buzzing in their bonnet they inaugurate a series of departments, for most of which no proper provision is made, and the cause of engineering education suffers with the rest. One such "university" gives three engineering courses and two other scientific courses with six instructors. Another school gives four engineering courses and one course in natural science with seven instructors all told. In another a professor and assistant give the pure mathematics and civil engineering. Other such examples could be given. In consequence of this instruction, or want of it, deluded students are graduated each year who labor under the belief that they have obtained an education which fits them for the practice of their profession. In many cases the knowledge imparted has qualified them to act only as country surveyors. Speaking now, not as an instructor but as an engineer, the writer wishes to unqualifiedly condemn such practices as a far reaching injury to the profession, and he would impeach the honesty of those who send broadcast over the land young engineering graduates who are not only wanting in knowledge of the fundamental principles of engineering, but who are unaware of their own ignorance of the subject.

This brings to our minds another tendency, having a different origin, but which acts in a lesser degree, to produce the same result. The opinion is often expressed that the practical engineer in his ordinary work never has occasion to use the higher mathematics; that his calculations are confined to the simple operations of geometry, algebra, and trigonometry. Does the skilled designer and constructor of difficult foundations, it is said, differentiate to find the depth to which he will sink them? Does the computer of stresses in the pieces of structures integrate to find them? Can you not proportion a sewer or determine the size of a water pipe by substituting in simple algebraic formulæ?

It is not only the uneducated engineer who makes this remark. It is heard as well from men who have had the best scientific education. And there is of course some truth in it. This basis of truth blinds many professional men and unfortunately some professional schools. They cry out: We are after the practical; we do not want theorists; we teach our young men the practical part of the profession and do not cram them with useless formulæ which they will never use.

The advocates of this method of education draw too fine a line between the suryeyor or the mechanic and the engineer. They forget the difference in the strength of the man who does a thing because some one tells him it is right and he who does it because he knows it is right. Even they would hardly say that the computer who knew only enough to take the size of a beam from a handbook was on the same plane with one who was familiar with the theory of flexure. And leaving this phase of the question out of consideration, although it is a fact that the ordinary routine work of the engineer depends largely on judgment and experience and involves simple mathematical operations, the time comes not infrequently when he should know how to attain results or make investigations which require an accurate knowledge of the higher mathematics, pure and applied. As a general statement, if he fails here he does not represent the highest type of the engineer. But it is the business of an engineering school to graduate young men so equipped that they shall in time, with experience, represent this highest type. It should, therefore, be the first aim of every such institution to ground well its students, not only in the fundamental principles of pure mathematics, but in those of rational and technical mechanics.

Few men of high grade in the profession look upon the higher text-books and treatises as ''heaps of mathematical rubbish.'' They cannot be so regarded in the professional schools of to-day. The use of them gives a solid mental equipment and grasp not easily attained otherwise. So equipped, the problems which bother the surveyor and the mechanic become child's play to the engineer. So trained, the forgetfulness of special methods of analysis which time perforce brings does not include that of fundamental principles necessary in his daily work. A smattering of so-called practical knowledge will never replace such a foundation as this.

It is the experience of the great majority of engineers—of almost all of them—that the exactions of professional work prevent them from giving much time to study and original investigation. In fact, the general statement may be made that if an engineer has not received in his youth a solid mathematical and, so to speak, theoretical foundation he will seldom acquire it afterwards. Furthermore, the early acquirement of such knowledge gives its possessor an added advantage. Acquirement becomes easy. All the more easy because the ordinary daily routine does not call into play his highest intellectual efforts. He enters the race not handicapped by a deficiency which would compel him to put forth his best efforts to understand the simpler problems of his profession, but his familiarity with these principles gives him time for that which is most valuable in all professions—a general consideration of the work in hand. Practical knowledge will reach him in due time. Whatever the course may be there must be few instructors indeed who think they are sending forth practical engineers. There is one way, and one only, to make a practical engineer. You cannot make one in the schools.

It is not intended to convey the idea that pure theory only should be given. Designs, experiments, tests, and surveys are valuable and necessary adjuncts. But they should not be allowed to overshadow courses in which fundamental theoretic principles are taught. They are adjuncts only and cannot replace these courses. For instance, the student of civil engineering should receive instruction in the design of bridges with estimates of cost, but only after he has been well grounded in the theory of stresses. If the time be too short too give both, all should be spent on the stresses. If he does not know the difference between a batten plate and a pilot nut it will not take him long to place them in practice. It is of more importance to him to learn in the schools the principles of the stability of masonry constructions than to be taught practically how to make concrete or lay masonry. Accurate knowledge of the strength of materials and of the properties of steam will give him a better foundation as an engineer than familiarity with the details of special engines.

This subject has been dwelt upon at some length because the writer believes that the attempt sometimes made to so educate a young man that he will step from school a practical engineer is abortive. If the custom were universal, the tone and value of the profession as a whole would be lowered. Its tendency in schools of civil engineering is to produce surveyors, and in those of mechanical engineering, mechanics, rather than engineers. It is perhaps more pronounced in schools of mechanical engineering than elsewhere, the tendency being to devote a large part of the time to pattern work, molding, and the machine shop. These render the student skilled of hand. May not too much of the time be given to hand work and too little to head work? The amount to be allowed for the shops and for testing is of course a matter of opinion, but it should always be remembered that there is a fundamental difference between the objects of a trade school and a school of engineering, and the difference between the curriculums should be not less great.

A few words at this point upon the proper use of models and apparatus may not be out of place. This would hardly seem to be necessary, but there is a growing tendency on the part of some schools to depend too largely upon their use. Valuable as they are for purposes of instruction, it must be remembered that it should be the object of an institution to send forth young men so equipped mentally that they will be able to take up and solve the difficult problems and questions constantly met with in professional life on their own responsibility. They can depend then upon no adventitious aid. If their reasoning powers have been developed by passing from the absract to the concrete, they will be more self-reliant and their judgment will be more liable to be sound than if they have been trained by the continued use of models and other similar aids. It is the quality of the training rather than the amount of knowledge acquired which should determine the value of a school. The use of acquired principles as instruments, not as collections of facts, is the desideratum.

In the academic schools of the country an interesting question has been considered during the last two or three decades. Difference of opinion still exist upon it and customs vary greatly. To what extent optional studies should be allowed in such courses has been a mooted point. To what extent specialization should be permitted in early training for professional life should likewise be carefully considered. Although the field of the engineer has become so broadened that specialists are required as in other professions, it is not considered wise to begin such differentiation at too early a period in the education of a young man. No one in practice can confine himself to one branch of professional work without continually making use of principles found in the others. Not only should the education in the schools be not too special but the engineer who has had a certain amount of practice in various branches of the profession is more likely to become eminent as a specialist than one whose theoretical and practical education has been confined within narrow limits.

Does a person who intends to become an oculist or a patent lawyer take a different medical or law course from one who intends to become a general practitioner? In order to become in the highest sense a specialist in the design of the superstructure only of bridges must not a man be, to a certain extent at least, a metallurgical, a hydraulic and a mechanical engineer? Certainly he must have more than even a general knowledge of these subjects. The difficulty with the average young graduate of our engineering schools is that his education is too narrow, too technical. It should at least be left broad enough to include a knowledge of the various branches of his own profession.

This criticism may be illustrated by an incident which came under the observation of the writer not long ago. In talking with a young man who was a few weeks afterwards graduated from one of our well-known schools of engineering, and who had just been testing the efficiency of the motors and plant of an electric street car line, the effect of grades was being discussed and he turned to the writer and asked, "How do you find the grade of a street?" Schools of course cannot always be held responsible for the idiosyncracies of individual students or graduates, but one could not help drawing the conclusion in this instance, that the course taken by the young man had been so warped in the direction of his specialty as to leave him ignorant of elementary principles of engineering which should have been ground into him, and without a knowledge of which his professional usefulness would be greatly curtailed. It is further to be remembered in this connection that much the greater number of engineers are not specialists, and that a large number of students who take courses leading in special directions afterward drift into other branches of the profession.

It may be said in general that the engineer is not liberally educated. Beyond his profession, his knowedge is not generally great. The writer believes the statement that the average man in any of the other professions is better informed on non-professional subjects to be a true one. The main reason is not hard to find. Very few of the young men entering our technical schools have had other than a rudimentary education. Very few indeed have had the advantage of an academic training. Even those who could readily afford to give their sons such a course, as a preliminary to one at an engineering school, will not generally do so. They are too eager to get them at work. This is a mistake, and until the school of engineering is recognized as a post-graduate one, it can hardly be expected that the engineer will take the rank among liberally educated men to which his professional work justly entitles him.

Recapitulating, it is thought that many schools add technical courses for the sake of having many courses and without making sufficient additions to their corps of instructors; that some of them, most of which are included in the class above referred to, give what should be called an elementary engineering education, but without using this qualifying prefix in their schedules; that others, from a mistaken notion that they can send forth full-fledged professional men, err by spending too much time on so called practical courses at the expense of that careful mathematical training so essential to the engineer; that some of them do not sufficiently recognize the radical difference between the school of engineering and the trade school; and that others specialize too much and do not in consequence give that broad foundation essential to the highest success. Finally, it is thought that to attain the best results a technical course should be taken only after the student has had the advantage of an academic training.

It is very easy to criticise, and the tone of the criticisms made above would seem to indicate that in the opinion of the writer the tendencies in engineering education to-day are largely unfavorable. Such is far from being the case. It was desired to point out very briefly certain of the more important weaknesses in some schools and systems, but it was not intended to convey the idea that these faults existed universally. Some of them do exist in each of the schools to a greater or less extent, but if one intimately acquainted with the methods pursued to-day in many of the better schools remembers that the first class ever graduated from a school of engineering in any English speaking country took up their professional work in 1835, and if he will compare the methods and courses of that time with those of the present day he will be obliged to admit that in this country technical instruction has kept pace with the general advancement in professional knowledge. A prospectus of the school referred to issued in that year gives the information that "the degree of Civil Engineer will be conferred on candidates of seventeen years and upwards who are well qualified in that department." Also that "one year is sufficient to obtain the degree" and that "graduates of colleges may by close application succeed in obtaining it in twenty-four weeks." These quotations show strikingly what advances have been made since that time. Improvements in the quality and methods of instruction are continually taking place. The schools are being brought more and more in contact with the profession. It is recognized that the instructors in the technical departments must themselves be familiar with professional work. And although not a tendency in engineering education, a most favorable augury which renders certain its growth and extension lies in the admission on the part of the profession of the necessity of the schools, and the constantly extending realization on the part of the people that a scientific education is the most fitting one for many of the pursuits of life.

COMPARISON BETWEEN AMERICAN AND EUROPEAN METHODS IN ENGINEERING EDUCATION.

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When invited several months ago to write a paper upon the above topic for presentation to this Congress the writer accepted in the hope that he might be able to devote sufficient time to the matter to prepare an essay of some completeness. Circumstances beyond his control, however, have conspired to prevent. A full discussion of this subject presupposes, of course, an intimate acquaintance with the methods in use in the various European countries as well in the various schools of this country. With the latter the writer is perhaps fairly well acquainted. Of the former his personal acquaintance is limited to the methods in use in Germany many years ago; and the time at his disposal has not enabled him to collect detailed information or statistics regarding present methods in the various schools of that country, or in those of France and England. With the schools of England, in fact, the author of this paper is so little acquainted that he must entirely exclude them from consideration, while his knowledge of the the French schools is limited to what can be derived from the various pamphlets issued by the *Ecole des ponts et chaussees.* There are present, however, distinguished teachers from several countries of Europe, and any errors which this paper may contain will doubtless be pointed out by them, and from the discussion which will follow we in this country may learn much regarding foreign methods.

This paper must of necessity be general in its character. Methods are not alike all over Europe, while in this country the greatest diversity exists. A paper might well be devoted to a discussion of the different methods in use in this country alone, so that a comparison between European and American methods must be simply qualitative, not quantative, and can only be made in a general way. In this comparison it will, of course, be necessary to refer to some extent to other subjects which have been or are to be presented to this Congress—such as the Ideal Engineering Education, Favorable and Unfavorable Tendencies in Education, and others. Methods cannot be discussed without reference to the material to be operated upon. Different materials require different modes of treatment. As in manufacturing (to quote a comparison recently made use of), the finished product in education depends also upon the material, the machinery, and the workmanship. The material is furnished to the school, the machinery and workmanship are what the school adds to produce the finished product. If the latter is defective, it may be due not to the machinery or to the workmanship, but to the material. A faulty piece of goods may, on account of poor material, be turned out by the best machinery with a large lot of perfect pieces.

The more uniform the material, the more accurately the machinery and workmanship may be adapted to its treatment, and the more uniform and certain the finished product will be. It is in the proper adaptation of the machinery and the workmanship to the material that the science of teaching consists.

THE STUDENTS.

Let us first, therefore, consider the material. Here we meet the first great difference between American and French and German schools, and the difference is much in favor of the latter. In our diversified country educational methods are nearly as varied as the topography and culture, and schools of nominally the same grade differ immensely in the quality of their work. Moreover, the profession of teaching is not recognized and appreciated here to the same extent as in Europe. Our active life and immense nervous energy hurry men into other pursuits; the financial emoluments of teaching are not what they should be; and too often only those men teach who cannot well do anything else. Reference is here made, of course, to teaching in preparatory schools. The points to which particular attention is now called are the diversity in preliminary training in this country as compared with the comparative uniformity abroad, and the higher degree of preparation required there. Many of our American schools draw their students from a comparatively limited area, sometimes almost wholly from a single state, and they are to that extent fortunate, especially if the fitting schools from which the students come are of nearly the same grade and character. Other schools, and especially the larger ones, draw their students from a wide range of territory. Perhaps only those teachers who are connected with such schools realize fully the extreme differences between preparatory schools in different parts of the country and between the training which has been received by students who have nominally studied the same subjects, and are able to pass in a way the same examinations. To mould into one homogeneous whole this heterogeneous mass of students, nominally possessing the same degree of preparation, yet in reality—apart from their own individual differences in ability—differing vastly in the training and development that they have received; to smooth out the inequalities and bring the class to as nearly the same level as possible, seriously hampers the progress of our higher schools, and requires work of them which ought to be done—and in Europe is done—by the preparatory schools. Some of the students possessing the greatest native ability are likely to be among those who have had the smallest amount of training—who have not learned how to study or how to think. To give these men a fair chance, as well as to weed out those who are not competent to continue their work, necessarily impedes progress. In this respect the contrast with Europe is striking. Then the preparatory schools there are better and more uniform in grade, the teachers are better trained and the students come to the technical school with approximately the same degree of preparation, knowing how to think, and with a thorough knowledge of the preparatory studies. That this is true is abundantly proven by the fact that at none of the German or Austrian technical schools are entrance examinations held—Zurich and the French schools alone requiring them. The certificate of a preparatory school of the proper grade is all that is required for admission.

The contrast is not less striking if we compare, not simply the uniformity, but the degree of preparation. The German student upon entering the *polytechnikum* has had as a rule nine years of thorough training, and is qualified to devote himself from that time forward almost entirely to professional work. He has completed the study of one modern language and sometimes of both English and French, has studied chemistry and physics, and in mathematics has always completed trigonometry and frequently analytic geometry, many students beginning at the technical school with a course in calculus. The writer believes that the students entering a German *polytechnikum* are from one to two years in advance of those entering our own best schools.

As is well known, the facilities for preparatory instruction are so poor in some parts of this country, that in preparing to pass even our entrance examinations, many boys require so long a time that they are nineteen or twenty years old, or even older, before they are able to enter, especially if they have been unable to study continuously, or have changed several times from one school to another. In Germany there is generally no required age for entrance, but when it is required, it is seventeen or eighteen years. In France, the *Ecole* *des ponts et chaussees* requires an age of eighteen years, but even at this age the students must have completed the the study of the calculus, as well as of mechanics and physics. In Austria and in Zurich the required age is eighteen years. In this country it is generally sixteen or seventeen. In Germany, the average age of students on entering the polytechnic school appears to be not less than twenty years, and is greater if the year of military service is passed beforehand. The writer has been informed by a professor in the technical school of Berlin that the average age of students at graduation is about twenty-six years (including the year of military service).

When we now remember that the courses of study in all the German technical schools cover four years; in Austria four years for mechanical engineering and chemistry, and five years for civil engineering and architecture, in the *Ecole des ponts et chaussees* three years—we are led to the conclusion, which would seem to be indisputable, that the continental technical schools are much more advanced than ours. By this the writer does not mean to imply that a young man who wishes to practice engineering in America had better go at once to a foreign school. On the contrary, he believes that several of our American schools will better prepare him for American practice than any of the foreign schools, since methods of practice here differ essentially from those abroad. What is meant, is that the continental schools carry the instruction in most technical subjects to a far more advanced point than is the case with us. This statement is indisputable, as has been said, and the foreign schools will continue to lead us in this respect, until our schools can command more thorough and more uniform preparation, and can raise their entrance requirements to a point approximately the same as those abroad.

The above statements will be substantiated by any one who compares the amount of time devoted to various technical subjects here and in the continental schools. In one German school we find the course on railroad engineering consisting of eight hours a week devoted to lectures and eight hours to drawing, during one year (about eight months of school work). This is considerably more than is given in any American school with which the writer is acquainted, the greatest amount of time here being the equivalent of six hours a week of lectures, and five hours of drawing. In the same German school, bridges and the theory of structures are assigned eight hours a week for lectures and six for drawing during one year, and four for lectures and seven for drawing during the following year, probably double that given in any American school. At the same time, indisputable as it is that the preparatory training is much more thorough on the continent, the age of students greater, and the technical courses more extended than is the case with us, these facts, nevertheless, cannot be said to constitute an unmixed good, or to be without disadvantageous results which go far towards off-setting the superiority which they indicate. The foreign student, upon completing his studies, is much broader than the graduate of an American school, but he has attained his breadth by the sacrifice of some of the best working years of his life, and instead of concentrating his mind upon the branch of his profession which he is to follow, he has spread himself over all branches of engineering, often in such a way as to induce superficiality. Certainly it is an advantage to a young man, even if at the sacrifice of some breadth, to begin his life work at the age of twenty-one or twenty-two, instead of waiting till he is twenty-five or twenty-six; and surely the average young American engineer who has graduated at twenty-two is, at twenty-six, after four years of experience, much more capable of doing, of achieving, than the German just out of the polytechnic. This view is shared by some prominent educators abroad, and a German friend of the writer's, whose name is known to many of those present, has very recently expressed his sense of the advantage which our students have in this respect over his own countrymen.

Having considered the preparation required, let us now turn our attention to the means and appliances for instruction—the *machinery* of the mill. These consist of

THE TEACHERS AND THE EQUIPMENT.

With regard to the teachers, the first point to be noticed is the greater number of professors in the foreign schools. While many schools in this country have one professor of civil engineering, and none have more than four in purely civil engineering branches, continental schools have generally as many as four, while some have as many as eight. The comparison holds for mechanical engineering, architecture and other branches. This is a direct result of the better preparation required for entrance, and of the more specialized instruction in the foreign technical schools. But while the number of full professors is greater abroad, the number of assistants and instructors is generally smaller than in our own larger schools, and always much less than the number of professors. In Munich, for instance, where there are two hundred and thirty-three students in civil engineering, there are but three assistants. The lectures are, of course, all given by professors, and most of the drawing and field work is also given by them; but the result of the small number of assistants (combined with the lecture system, which will be discussed later) is, that the student receives less individual instruction and attention than is the case at our best schools. Indeed, in some of the German schools field surveying parties were, not many years ago, sent out with so many students to one instructor that most of the men devoted themselves to surveying glasses of beer in a neighboring *Gasthaus*. This matter will be again touched upon in considering methods of instruction. It will suffice here to say that the foreign student needs less personal attention than our students do. He knows better how to think and how to study, and is much better qualified to take in and assimilate knowledge when it is merely presented to him.

With regard to material equipment, the European schools, on the average, are apparently better off than our own. The explanation is clear. Many of our schools, supported by the state, are too often dependent upon the ideas of legislators, some of whom are no more able to appreciate the value of a testing machine or of an engineering laboratory than they are to understand the higher mathematics, and the educators in charge of such institutions have frequently to resort to every possible device to demonstrate and illustrate the necessity for such equipment. The masses of the people in many of our states are far below the degree of enlightenment necessary for the proper appreciation of a technical school of high grade; and it is the people who, through their representatives, control the state universities. On the other hand, some schools founded by private munificence, or otherwise supported by private funds, are not able, through lack of means, to furnish equipment, the educational value of which may be fully recognized by those controlling these institutions.

On the continent the great technical schools are all supported by the states, which vie with each other in securing the highest degree of excellence in equipment as well as in instruction. In fact, it has been thought by some keen observers that there were too many polytechnic schools in Germany, and that better results would be attained with fewer and larger institutions. Apparently, however, the desire of each German state has been to have as good a *polytechnikum* as it could provide, and the importance of a good equipment, in teachers and apparatus, has been fully recognized by the officers of these governments. The sums of money at the disposal of some of these schools have been apparently almost unlimited. In Berlin the new building for the royal polytechnic school was completed in 1884, at a cost of over two million dollars, and some other schools have buildings and laboratories almost as fine. In some of our larger schools, nevertheless, the equipment for instruction is certainly as good as in any school on the continent, and in the use of laboratories for purposes of instruction in engineering we are far in advance of our continental brethren.

METHODS OF INSTRUCTION.

We come now to the third and last topic to be considered, namely, the *workmanship*, or the *methods of instruction*. To this one topic this paper ought perhaps to have been devoted, were it not for the fact that, without the statements that have preceded, the methods of instruction could not well be discussed.

In comparing our methods of instruction in engineering with those in the continent, the following is a general classification of the main points of difference, so far as the writer has observed them:

First. Abroad, the main object of the instruction in many branches appears to be to impart information—to offer the student food, but to leave him to his own resources in devouring and assimilating it. Here, the main object is to train the student to think.

Second. Abroad, laboratory work is not made use of as a means of instruction to the same degree that it is here.

Third. Abroad, the student is absolutely free to choose his course of study, and is required (generally) to pass no examinations unless he seeks a diploma.

Fourth. The technical curricula in the great continental schools are broader and more general in their scope, technically, than the courses in our own schools.

Let us consider these points in order:

First. INFORMATION *v.* TRAINING. American engineering educators will probably agree that the main function of our engineering schools is to give training. A school cannot make an engineer, and few claim to do so. In order to be an engineer, a man requires four things: Judgment, experience, knowledge and training. Judgment, no school can give, though it can train the judgment to accurate and careful habits. Experience the school cannot give, but it can train the student to assimilate and make use of the experience of others. Knowledge, it can give to a certain extent, but best of all, it can give to one qualified to receive it, a training which will enable him to think clearly and to acquire knowledge rapidly. With a naturally sound judgment, and with the training which a good school gives, such a young man should possess a foundation sufficient to sustain the most lofty structure of knowledge and experience which can be built upon it, and ought to be able, in a very short time, to become an engineer and a good engineer.

Among the most unfavorable tendencies that are to be noted occasionally in engineering schools is the tendency to substitute information for training. With the degree of training which our students at the present time bring to the technical schools, such a tendency, if carried out to any very considerable extent, will, in the writer's opinion, always prove fatal, resulting in rule-of-thumb methods, and a smattering of engineering practice which is only a cloak for ignorance of principles.

One of the greatest advances in the theory of education, however, has come from the gradual realization of the fact that opportunities for training are found, not alone in the old scholastic studies of the classics, philosophy, and mathematics, but that they are as numerous as the possible subjects of study. The good teacher of any subject whatever, will be able to make it an opportunity for training of some kind. The various sciences and their manifold applications, no matter how closely allied to commercial pursuits, may, as we all know, be made the means of training even better than systems of philosophy or the theory of functions. Less than a year ago a very distinguished professor in one of our colleges publicly expressed his profound regret that one of his colleagues had devoted himself to the commercial applications of his chosen science, instead of to pure science alone, thus (he said) greatly lowering his ideals. Such views are relics of the dark ages of education, and are happily becoming less and less common.

Probably all of our engineering educators recognize the importance of training. In different schools, however, or in different parts of the same school, the amount of training given varies considerably. Some schools devote considerable time to descriptions of details of construction and of operation, as such, merely as matters of information, while the lecture system, pure and unadulterated, is still used to a considerable extent where, it seems to the writer, it ought not to be. We still frequently see in our schools immature young men, unable to think or reason accurately for themselves, capable of being misled by sophistries at every point, and conducted to any conclusion which the lecturer might desire. We still see such men listening to a discourse from some eminent lecturer, involving fine points of logic and intricate processes of reasoning, and supposed to be assimilating it all. The writer's views regarding the lecture system are perhaps radical, but they are the result of many years' use of that as well as the other systems of instruction. He looks upon the simple lectures as almost useless as a means of training, and as simply a means of *presenting* facts and arguments. A trained mind may listen to a lecture on an intricate subject and profit thereby, while an untrained mind would gain little or nothing. Lectures should be used only for purposes of demonstration in experimental subjects, or for purely descriptive subjects which are not claimed to be training subjects, and which we, in our schools, have time to introduce only to a very limited extent. Sometimes, however, circumstances may, for a time, prevent the use of any other method; as, for instance, when no satisfactory text-book is available and there has not been opportunity to prepare one; but in most cases the lecture system, pure and simple, should be modified by preparing to some extent cyclostyle or other notes, by allowing the students time to take notes, or to copy what is put upon the blackboard, and to ask questions, and by occasionally quizzing them during the lecture, or sending them to the blackboard.

It is doubtless true that occasional lectures, if well considered and well presented, often serve a good purpose in imparting interest to work that might otherwise be dry, and in inspiring enthusiasm in the listeners. A good student will sometimes leave the class-room after listening to an eloquent lecture, filled with enthusiasm for investigation and research, and will bend all his energies to the work before him. But the poor student, or the man who needs help and not mere suggestion, who cannot work by himself and does not know how to think, he will get little benefit if he tries to master any mathematical or theoretical subject by listening to lectures.

In the writer's undergraduate days, both here and abroad, he listened to many courses of lectures, but he does not remember in any single case to have made use of the voluminous notes he took; nor does he believe that any large proportion of the students who listen to lectures in our technical schools ever make use of their notes afterward, or in fact take notes in such form that they can make use of them with reliance upon their accuracy.

The great distinction between continental and American schools in this respect is, that in the former lecturing is the common mode of instruction, combined, of course, with drawing and field exercises in some subjects. In some mathematical subjects there are hours devoted to solving examples, and almost all the instruction is still in the form of lectures. During the the three years the writer spent in a German polytechnic school no instruction was given except in this way and in the drawing room. There was no recitation work whatever. The teacher never asked the student a question or tried to find out whether he was thinking correctly. During these lectures the students are supposed to take copious notes, which they generally do in ink, and these notes are frequently not written up afterward. The question arises, how much of one of these lectures could a man really take in at the time, while writing with all his might and main to take down what the lecturer said or put upon the blackboard? Some of the professors publish their lectures, either in book form or as lithographed sheets, but this fact does not affect their lectures at all; they go over in the lecture precisely what is given in the book, the latter not being used in any sense as a text-book. In fact, in some cases the purchase of these notes is not obligatory; they are simply provided for those who wish them, and many indigent students do not procure them, but depend entirely upon their own notes. Many students went entirely through the polytechnikum at the university without purchasing a single text-book, but came out with voluminous notes on the calculus, and on all the engineering courses. Even courses in complex mathematical subjects like the theory of elasticity and hydrodynamics, with equations as long as your arm, were given by lectures and the equations all written out on the blackboard in the course of the lecture, the students eagerly copying.

In connection with the lecture system, one other disadvantage which it possesses may here be noticed, namely, the lack of personal contact between the student and the instructor. It is a common characteristic of our schools that the students come into close personal contact with the teacher, learn to know him well, and, if he be the proper kind of man, learn to look up to him and are inspired by him. The same is true in Germany, in those courses in which the lectures are accompanied by drawing-room exercises. In purely lecture courses, however, the teacher lives entirely apart from his students; he comes to the school at the appointed hour, with his notes in his pocket, gives his lecture and goes home or to his room, his duty to the students beginning and ending with his lecture. The writer looks upon such a system as unfortunate. One of the great advantages which he thinks is derived by a student in our schools is the inspiration and enthusiasm which come from personal contact with a good teacher. He remembers that in his undergraduate days he felt it so, and he felt distinctly the loss of it in Germany.

In addition to the use of the lecture system, and as a partial justification for it, the foreign schools give a great deal of instruction that is merely detail, and cannot claim to be training at all in the way in which they give it, that is, by lectures. Instead of referring the student to some book where he can find these details, and telling him to look them up, or instead of furnishing him with prints of these details, they are all drscribed in the lecture and depicted upon the blackboard—at least, so it used to be. This instruction in details is carried to a very advanced point in both France and Germany. Regarding this, however, since it is carried on, not at the expense of principles, but in connection with principles, it is a point of superiority in foreign schools except in so far as it involves the expenditure of a large amount of time. Much time could be saved by the use of a text. Several of our own schools have the practice of distributing, if not printed notes, at least blue prints or cuts of the details to be considered, so that the student is not obliged to copy them from the blackboard, and the lecture can be devoted to a discussion and comparison of methods.

If properly done, the teaching of details can be made a means of excellent training. The main duty of the school, however, should be to teach the student the things that he cannot learn by himself, or that he probably will not learn by himself, besides training him to learn by himself. This means the teaching of principles—not necessarily purely abstract principles—but principles in connection with their applications, so that the principles themselves may be clearly grasped. In fact the writer wishes here to say that his own strong belief is that no teaching should be purely abstract, whether in a technical school or in a university. To teach *pure* mathematics, that is to say, mathematics simply as an abstract set of principles, for no end and with no illustration but themselves alone, seems to him to be fundamentally a fallacious and evil practice in education. "It is through its practical value," say Professors Ayrton and Perry, "that a knowledge of mathematics must come; and any teacher who refuses to consider the instinctive preference of his pupils to reason about things rather than about ideas, is a man who persistently refuses the powerful aid of nature." And again, Professor Huxley says, "The danger in all these technical schools in this: that the teacher generally begins his work on the high and dry method, and fills the mind of the student with mere verbal formulæ before there is any practical experience by which these ghosts can be embodied."

Schools in this country have not the time, as a rule, to teach much beyond principles, accompanied by a sufficient application to enforce and emphasize them. They cannot, as the continental schools do, carry the students through a long course in details. To this extent they are inferior to the foreign institutions, and to this extent their graduates are less prepared to enter at once on the practice of their profession. It must be acknowledged, however, that the student who is thoroughly grounded in principles can and will —yes, must—pick up these details by himself after leaving the school, so that the lack of them does not at all interfere with his ultimate success, which is the main end to be attained. Moreover, most matters of pure detail can be learned better and more quickly in actual practice.

As regards the point that we have thus far discussed, the writer need not say that he regards the American system (if he may call it so) as superior to the European. Each, however, is applied under different conditions, and is, perhaps, the method best suited to those conditions. The continental students enter the technical schools one or two years older than ours at entrance and they have also had a better training. They know how to think, and can and do assimilate a great part of the theoretical work that is given them, besides gaining a good knowledge of details, but they get little training in their technical courses, except what comes from their own study. We take our students with much less preliminary training, often very poorly trained or not trained at all. Our courses are, therefore, principally for training, with as much detail as we have time to give, or as much as is necessary to enforce the principles. While, therefore, the foreign schools carry their instruction in technical subjects much farther than we do, theirs is largely instruction in details, which we are obliged to leave the student to pick up by himself. In the study of principles, it will be found that while still ahead of us, they lead our best schools only by a few lengths, while in some respects, one or two of our schools are, perhaps, ahead of them. The American student has gained upon his competitor during his technical course. Considering his years, he is, at graduation, ahead of the foreigner. He will, in actual practice, learn the details of engineering work much better than the foreigner has learned them in the school, and when he is as old as the German is at graduation, he will, as already remarked, be a man more capable, as a rule, of doing work and attaining results.

The German system would not be successful in this country. The writer does not hesitate to say that, were it attempted to treat our students by this process, the result would be simply disastrous. The bright, mature, and well prepared men might learn as much as they do now, or even more, since there would be a gain in time due to the partial abandonment of recitations, and more ground could consequently be covered in the same time. But the average man, if he kept along, would find himself gaining little in power, and though he might be gaining information, it would be without a thorough understanding of the principles. The method works in Germany, and gives excellent results. That it does so seems to be due simply to the preliminary preparation the students receive. Only a young man who knows how to think and study can take such a course to advantage. Therefore, it may be said to young men who ask about going to Germany, "take a technical course here first, and then if you wish, go to Germany and broaden yourself." The foreign method is suited to foreign conditions and our method to our conditions. But, while each is successful in its place, the writer feels very strongly that ours is the better method and that even in Germany still better results than are now attained would result were the lecture system not so freely used.

No reference has been made here to the advantages for post graduate study of special subjects in the German schools, which are often great, but there has been considered solely the ordinary undergraduate course.

Second. LABORATORY WORK.—The second point of difference to which your attention is called, and in which the comparison is much to the advantage of our schools, relates to the introduction of laboratory work as a means of instruction. It has already been said that the good teacher would find opportunity for training in teaching any subject. Not only is this true of laboratory work, but we in this country have come to realize strongly that there is much more to education than training the mind by mere book knowledge. In order to develop the mental and physical powers symmetrically, the powers of observation, the hand, the eye, should equally receive attention. The student should be taught how to observe natural phenomena. to carry on experiments and to reason from them, and should be encouraged in devising new methods of investigation. If the writer is not mistaken, the introduction of laboratory methods of instruction in the teaching of elementary chemistry and physics—methods which have revolutionized the teaching of those subjects—first occurred in this country, and the same is true regarding the laboratory teaching of engineering. Several of our schools are now equipped with extensive laboratories for testing the strength of materials, for experiments in steam engineering, and for carrying on hydraulic experiments; besides which, field measurements in hydraulics are carried on by a few schools, all of this work being done by the students as a part of their regular course. To the best of the writer's knowledge, such work is done scarcely at all on the continent. Some of the schools have testing laboratories, but they appear to be principally for private research and for commercial tests by the professors and their assistants, and not primarily for the use of students. It is not long since the same was said to be true, to a considerable extent, of the laboratories of physics and chemistry, in which specially favored students could obtain good facilities for work, but which were at least not used for the regular and systematic instruction of the classes, to the same extent as they were with us.

The writer's information as to the extent to which laboratory instruction in engineering is made use of abroad is very incomplete. At Berlin and at Zurich there are testing laboratories, but they are used almost entirely for commercial or scientific work. No use is made of them for regular instruction, though exhibition tests are made before the students at times. At Hanover, Dresden, and Munich, there are hydraulic laboratories of some kind, but how extensive they are, or how much used by the students, the writer is unable to state. The only steam engineering laboratory that he heard of on the continent is at Munich.

In laboratory instruction, therefore, if not in laboratory equipment, we are far in advance of our continental brethren; and this, if too much time is not devoted to the work, should and does result in a corresponding gain in training. It should be said, however, that among the tendencies in our schools, one which seems to be distinctly unfavorable is the tendency to use laboratories too largely for purposes of extended original research carried on by students. In the writer's opinion the primary purpose of a laboratory should be to afford the student opportunity to see clearly and understand thoroughly how the various engineering tests are carried on and worked up. To do this, certain tests must, of course, be carried out completely. But any original laboratory research, to be of value, generally requires a large number of tests of the same kind, to carry on which the student is obliged to do the same thing over and over again, perhaps a hundred times if the research is to be of value, thus absolutely wasting his time with little commensurate gain.

In other words, the primary purpose of a laboratory in a school, like every other part of its equipment, is instruction and training, not research in itself; and any investigation—like one, for instance, which requires a student to make and break one or two thousand cement briquettes—is, it seems, a loss of time.

Third. STUDIES, EXAMINATIONS, AND THESIS.—The third point of difference to which your attention is called relates to the arrangement and choice of studies and the matters of examinations and theses.

In Germany, as in some of our own schools, each student is free to choose his own course; certain courses of study extending through the four years, as in civil engineering, etc., are, however, laid out, and the students are advised to follow them. As these courses are generally followed, this method need not be compared with our own, in which certain fixed four-year courses are open to the students.

In Germany, moreover, there are in most schools no compulsory examinations whatever. In fact, no oversight whatever is exercised over the students' progress, and after entering the school he is allowed to do as he pleases, learning as much or as little as he wishes. In the *Ecole des ponts et chaussees*, however, a very strict oversight is exercised over the students, both as to regularity of attendance and as to their work.

The writer cannot regard the German method in this respect with favor. In this country, where our students are younger and where many go to school—not to learn, but because they are sent—it would not do at all. It works in Germany, like the lecture system, because the students are better trained and more mature, and also because the Germans are naturally more earnest and more inclined to study and investigation than we are. In our schools we have to weed out students who are incompetent to go on, students who on account of laziness or bad habits are prejudicial to the interests of the rest of the class, and students who will not work, but come to school because their parents send them. The writer has never heard of a student being dropped from a German school. He has no doubt that they have students whose habits are bad, and who are incompetent to go on, and some who are lazy and will not work. Such men, however, are left to follow their own devices, without any supervision, and they soon drop out and seek more congenial associations.

In most of the German schools examinations are held for those who desire a diploma. These, as well as the examinations for government service, are generally held in two parts, one at about the end of the second year, and covering preparatory subjects, and one at the end of the course, covering technical subjects. These examinations are long and severe, and often involve the detailed working out of some project.

Without discussing this practice at length it may be said that according to American experience it does not seem wise to concentrate at one time a severe and trying examination covering a number of subjects, some of which the student has studied several years before. Neither does it appear wise to require a student to pass a severe and trying examination on all branches of civil engineering. It tends to superficiality rather than breadth, in many cases. The judicious introduction of options would be especially appropriate.

Theses are not required at German technical schools excepting the project which has to be worked out as part of the examination. The whole time of the course is given entirely to instruction. Probably all of our schools require theses for graduation, which are prepared during the school year as a part of the regular work. Something may be said in favor of abandoning the requirement of theses, especially if, as appears to be sometimes the case, the student in preparing his thesis is thrown entirely upon his own resources, without aid from the instructor, and if considerable time is devoted to the work; or if the subjects of theses are so selected as to involve doing something, perhaps many times, that the student is already perfectly qualified to do. If, however, the thesis is made primarily a means of training and instruction; if the subject and the mode of carrying it out are under constant supervision of an instructor, and made to involve no loss of time, then we should probably agree that its preparation is a fitting and advatageous close to the student's work, affording him an opportunity to gain practice in systematic thinking; in the proper arrangement and presentation of his thoughts; in the writing of his native language, in which our technical students are often very deficient; and to gain some useful knowledge of the special technical subject selected for investigation.

Fourth. COURSE OF STUDY.—The fourth and last point of difference to which I will call your attention is this: Owing to the fact that so large a portion of the time is devoted to purely technical work, instead of being filled up, as it is here, with linguistic and general studies—the technical courses of study are in general broader than they are here. The student of civil engineering gets a good deal of instruction in architecture and in mechanical engineering and *vice versa.* This is, of course, an advantage. There is time, in the foreign schools, to carry the instruction in each subject to an advanced point, and yet to require students to take many different subjects in four years. In our schools this is not possible, owing simply to our low requirements for admission; and where the time is limited, it seems wise to give thorough courses in a few subjects rather than short courses in many.

CONCLUSION.

We see, therefore, that while there are great and radical differences between European and American methods, each is adapted to the condition it has to meet. We have much to learn from European schools, and doubtless they have some things to learn from us. Our technical instruction is in able and progressive hands, and it can be expected to advance in efficiency as rapidly as circumstances will allow. The principal improvement in technical instruction in this country, however, must be looked for through an improvement in the lower or preparatory schools, and a raising of the standard of training and knowledge required for admission to our higher technical schools.

DISCUSSION.

(Of the papers by Professors TALBOT, RICKETTS, SWAIN, and BURR.)

PROFESSOR JOHN GOODMAN (Yorkshire college, England) referring to the paper by Prof. Swain, said he thought Prof. Swain should alter the title of his paper. The remarks he made with respect to the continental European schools might hold, but they certainly did not hold as to the English schools. He believed that the work of the English schools were far ahead of the teaching in the continental schools, and he also believed that they have very much to learn from the American schools of engineering. When first appointed to the chair of engineering of Yorkshire college, he was speaking to one of the Royal commission of the Chicago exposition, who said to him: "Now, the very first opportunity you get, go over and see what the Americans are doing, and you will see there technical education carried out with the greatest efficiency." He had accordingly visited all the technical schools in the Eastern States, and he must say he was strongly impressed with what he saw. He was hoping to go and see other schools in the United States and hoped to be able to get still further information. The general opinion in England is that the teaching on the continent is not as practical as it ought to be. He believed that the purely theoretical training is carried out there further than is required. He knew, for example, in one of the continental schools of engineering, where certain of the professors occupy three or four lectures in working out very completely the strength of a link of a chain. One of the students came over to London and went to work for a crane maker, and the proprietor said to him early in the morning: "You may just order sent one hundred feet of chain capable of carrying ten tons." Later in the day, he came and asked the fellow if he had ordered the chain, and he said "no, I have not; I have been figuring it out," and he had used something like two or three quires of foolscap calculating the stresses of all sorts, to find out the dimensions of that chain. The crane maker, taking a book or envelope, said: "Here, that is how to do it," and did it in half a minute. That was the general tendency, he believed, of the continental schools. They train men in such a way that they go into absolutely unnecessary work, and they totally neglect the practical side of engineering work. That is the general impresssion in England, and not from mere heresay. He had visited all the technical schools on the continent, and had very carefully noted their methods of study and work.

Professor Swain had said that the laboratory system is not so thoroughly carried out in Europe as it is in the United States. On the continent of Europe he would admit that it is not, but in England he was quite sure that it was utilized in the highest possible way. He had a one hundred-ton testing machine that would take in bars up to twelve feet long, and they did thoroughly practical work on the largest possible scale.

Then as to Prof. Swain's remarks on lectures being almost useless, he must differ with him there. If the teacher is a man who mumbles and cannot speak properly, then, perhaps, recitations may be better: but with men who have abilities as teachers, it seemed to him that they must have a very much greater power in lecturing than in any amount of mere recitation work. As to text books, he had never came across one that met the requirements. If a text book satisfied him today it would not satisfy him twelve months hence. The world was going forward. Better methods are coming out year by year. Teachers must improve as they go along, and not stick to text books written thirty or forty years ago. We have infinitely better ones now, and our methods of teaching are infinitely superior to Rankine's. Where he went a long ways about it to prove some simple matter, we go right to the point. It seemed to him that the reciting of the text book cannot have the same effect as instruction by lectures.

As regards the use of note books—that they are simply written out in pencil or ink, and then thrown aside, that may have been the case in some institutions. In England, they are very careful with their students in making them keep their note books up to date, and they have well-bound books with good paper, and this made a good deal of difference. The student took his notes fully, as fully as necessary during the lectures, and periodically sent in his note book to the lecturer. He must keep up to the mark in copying full notes, and doing it the same night, if possible. In the case of tabular matter and illustrations they give the students printed matter, and if it is necessary to refer to some complicated bridge structure, photographic prints are used. They also use the lantern. They have complete sets of lantern slides to illustrate all their lectures. They give them photographs also, about the same size as the lantern slides. They stick these in their note books, and also, by the side of these, diagram sketches showing the main features, in the form of a print.

In regard to laboratories, he confessed that in some of the continental schools the mere exhibition is used more than it ought to be. That, however, was not the case in England. Sometimes during the lectures with elementary students they do take them down into the laboratory and show them the physical characteristics of the various materials. After that, the men go there and make experiments themselves. He thought that Prof. Swain was mistaken when he said that the only steam laboratory on the continent is at Munich. He believed that nearly all of the technical schools in Europe now have experimental steam engines of the best possible type.

In regard to the examination system, he believed the ordinary examination system of simply setting a paper and giving a man three or four hours to answer the questions is radically bad. He thought it was no test whatever of a man's knowledge. In his own practice, for the first term examination, he gave the men a problem of some actual work to carry out, and gave them a week in which to do it. Each student sends in his papers with a statement that he had had no assistance whatever, and full notes as to how he has arrived at it. This is all that is done at the end of the first term's work. After the second term's work he always gave a set of problems and allowed them to use their own note books; it enabled them to do what they all have to do in after life. If a man wanted to get out any design, he did not set to work without a single note or single help of any description, but he searched up his note books and other text-books. This method put a premium on the note-books. Then, for the third term's work, he set the ordinary paper and it is done in the ordinary way: a certain number of questions, and generally a whole day—giving them perhaps a dozen or twenty questions—and half of them to be answered, giving them plenty of time in which to do it.

He did not believe in the rushing system. It was not at all the test of a man's real ability.

Professor Bull wished to add something from his own experience. He had spent four years in Zurich, and he knew there was a good deal of difference between the German and the Zurich schools. He agreed fully with the method of examinations. Not requiring any examinations in the second, third and fourth years, he thought it was liable to make the students lazy, but in Zurich, besides the lectures, they have reviews one hour a week, at which they are compelled to be present. If they are not present, and it should appear that they do not work, they are very soon sent away. They are fully as severe there as here. There is the remedy. Besides all of this, they have examinations at the end of the term, and by means of these examinations, especially the reviews, the students come in personal contact with the professor.

As to compelling students to do some work, it is a good thing. Last summer he had been on the continent and he had met an old acquaintance who used to be an assistant in Zurich, and who is now a professor in Munich, in charge of the steam engine laboratory there. He had inaugurated the same methods in Munich as were in vogue in Zurich. The speaker fully agreed with Professor Swain. There were engines in Berlin, Munich, and Zurich, but the only proper steam laboratory was in Munich. That was the case last summer (1892). In Berlin some advanced students do a little work with gas engines and so on, but you only find one real steam engine laboratory, and that is in Munich.

Dr. H. T. Eddy said he could conceive the hesitancy with which the gentlemen present would rise to discuss these papers which have treated the subject with such elaboration and care, and such admirable good judgment, and he thought this explained the difficulty the chairman met with in finding persons to discuss cursorily, and in the main, subjects of such very great importance as these which had been laid before the section. Perhaps the thing which he desired to say most was how thoroughly he agreed with the sentiments and expressions which had been already presented. With these sentiments and ideas most of those present doubtless fully agreed, although they might not see how in the present stage of technical education, to carry out all that they unitedly desired to see carried out. It was, he believed, customary in English societies, whenever a paper was read, to criticise it severely. He felt that the trend of criticism in this country was always a little different from that, so far as his observation went. He knew that Prof. Swain was so modest that he would allow the speaker to state a word in his behalf. He had very distinctly disclaimed following the title of his paper,—he wanted it distinctly understood that what he said did not apply to English schools, as he was wholly uninformed in regard to them.

As to Prof. Burr's paper the speaker agreed with him fully as to the present and future possibilities of the profession of engineering, and which rests so largely in the hands of the educators,—the engineering educators—and when such a spirit as he exhibits, such aspirations as he has voiced, are those of the engineering educators, we must feel that engineering as a profession is to enter into the great field which we all hope and believe it will occupy. The field is widening, the needs of modern life are constantly growing larger, and it has been greatly added to by electrical engineering in the most recent times, and on the part of this conference he hoped it might be added to in the aerial fields in the almost immediate future. He felt that these congresses and the work of their several divisions, have helped us very greatly towards new ideals. Those who have felt that they were somewhat beyond the present realization—have felt perhaps, they were a little cranky—have had their faith straightened by exchanging views as we have here to-day.

PROFESSOR J. B. JOHNSON said he had long hoped that the teachers of engineering might accomplish something in the way of establishing standand requirements for entrance and for graduation in our engineering schools, and the minimum of plant and of instruction which should lead to graduation from such a course of study. This would greatly assist those who are now trying vainly to raise their standard but who are prevented from so doing by the powers above them. Doubtless all are doing the best they can under the circumstances. What we need is some way of changing the circumstances, but it could not be done by an occasional meeting of this kind. He believed, however, that this was the most significant meeting that technical educators had held in America. He believed that all felt the importance and dignity of this series of meetings, and he hoped that something permanent might grow out of them, something in the nature of a permanent organization of engineering instructors. He had understood that Prof. Robinson had something of that sort to present and he had made these remarks only as an introduction of the subject of a permanent organization. Doubtless all would like to carry out the ideas advanced in the papers, but all of them could not do what they would like. If, however, they could bring some suggestions and decisions from some organized body of engineering educators before their home people and before the authorities of their institutions, such a body would become an important agency, with very great weight in shaping future developments of technical education in America.

The chairman said that arrangements had been made for the presentation of the organization of an association of engineers at this Congress for the promotion of engineering education.

Professor S. W. Robinson wished to emphasize one truth stated in Prof. Burr's paper. Laboratory studies are coming on to be a very important thing in our schools. The point is, we should study in college those things which we are not so likely to study and familiarize ourselves with in practice, and leave those things we are more likely to learn in practice to that practice: give attention to the study of those things likely to be overlooked in practice, that is, theoretical training. Thorough theoretical training is the prime essential. If we are obliged to omit anything, let it be the laboratory. He thought it was a very important consideration not to neglect the laboratory altogether, but let that bear on the enforcement of the principles of the study rather than experiments for investigation, and in training the student in systematic ways of keeping notes, etc., and devote his other time more to the study of principles.

Professor S. B. Christy thought no one who had listened to these papers, especially the last one (by Prof. Burr), could fail to feel a sense of satisfaction at the manner in which the real essential dignity of the engineer's profession had been presented, and the importance of coming to some common agreement as to the ideals, purposes, and methods of instruction on the part of those engaged in the education of engineers. In that connection he wished to call attention to one phase of the subject that had not been as yet suggested, and that was the advisability of coming to some agreement as to the conditions on which engineering degrees should be conferred. He had one suggestion to make in that connection. It had been generally recognized that a technical school could not graduate engineers—that they simply graduate men who are prepared to become engineers. Now, if students are given professional degrees on graduation, it is evident that they must become engineers at the expense of their employers. It seemed to him that it was a mistake to grant such degrees, and it lowers the dignity of the title.

THE CHAIRMAN remarked that this subject was down for discussion on Friday morning.

PROFESSOR CHRISTY continued his remarks and spoke of the lecture system. It seemed to him that Prof. Swain was generally and entirely right as to what is usually given in the way of lecture instruction, but it is not, it seemed to him, essentially a bad system. He recalled to mind instruction that he received in hydraulics, which was chiefly by the lecture system. He could not imagine a better system, in the hands of the man who managed it. He knew that he went to the lecture room with no notes and lectured for two hours and held the whole class intensely interested even to fascination. He did not give a studied lecture; he had the whole matter entirely in his mind. He would call first on one man and then on another in the class, beginning at a fundamental principle that they all agreed on to develop the subject matter; he reviewed it as they talked it over, and would illustrate it as they went along, and in that way it was the most efficient instruction he had ever seen and entirely on a mathematical subject.

He wished also to say that he heartily agreed with the points made by Prof. Goodman on the question of examinations. It had been originally suggested to him by Dr. Becker of the geological survey, and was essentially this: The students are allowed to bring to the examination any books they choose, and they have the whole day to answer the papers, and it is astonishing what the effect is upon the students and examiner. If the students are allowed to bring books of reference, it forces the examiner to confine his questions to such as are not found in books of reference, and he knew of students taking examinations of this sort the first time, when they came into the room with a whole armful of books and were very much surprised to find that they did not help them.

Another point that was of great interest to all was the point brought out by Prof. Burr, viz: "The General Culture of the Engineer." He thought all would admit that this should be an essential part of an engineer's education, but it is one of the most difficult things to right in our American technical schools. It seemed almost impossible to require a general college education as a prerequisite for the engineering school; under American conditions it seemed practically impossible. He would like to have some general expression as to what should be the minimum requirement to enter an engineering school; also what amount of technical instruction should be put in the under-graduate course. It seemed to him that a more definite statement was very desirable.

Professor C. Frank Allen had something to say that perhaps nobody else could say quite so well. When he returned to the Massachusetts Institute of Technology about six years ago to teach, he found teaching there a professor who, on a mathematical subject, stood before his class with chalk in hand, without notes, and was able to hold the attention of his class without any difficulty whatever for two hours. About five years ago, he was told by that professor that he thought that was the proper way to teach that subject, in preference to teaching it from text-books or from printed notes. That professor was Professor Swain, who now tells you freely that the lecture system for that purpose is not the system, but that teaching from the text-books, with such supplementary lectures as may be necessary, is the better way. Professor Swain tells you now that, in his opinion, this is the proper method of teaching.

Professor DeVolson Wood said, since we have two feet, what is the use of compelling ourselves to walk on one? It is not necessary, as he understood it, to confine ourselves to lectures to the exclusion of the text, nor to the text to the exclusion of the lectures. Much may be left to the disposition, experience and surroundings of the professor. For his own part, if he should exclude one or the other, and walk only on one foot, he would exclude the lectures and use the text, but he treated neither himself nor his students in that way. The text formed the core, the nucleus, the thing that he stood by when he had nothing else to say, and when he had something else to say, he said it. The question, therefore, with regard to the abstract part, need not be discussed by itself. There was no danger, he thought, of having too much mathematics in any of our courses. It was a question with many whether the calculus was of any practical use to the engineer. Many said that it might better be eliminated. He had met practical engineers who deprecated their using so much calculus in the colleges—said they had never used it. The speaker thought there was no danger of having too much mathematics.

In regard to laboratory practice, he thought much good, sound sentiment had been expresssed, and in connection with that he would just hint that in the use of apparatus there may be too much stress laid upon it. The fixed and universal should never be sacrificed for a knowledge of particular methods and devices which may soon be superseded.

If we were to teach only what has perpetual existence we would teach principles, for principles never grow old. If Rankine's books are forty years old, the principles are there. We possibly might have better text books for our use to-day to present those principles, but we must establish in ourselves the principles. A man who studied in the schools and went out to practice, had said to him with a good deal of earnestness, "If the schools don't teach something that you cannot get in the shop, there is no use of them." He thought the position was well taken, and that is one of the reasons why we may teach ideals, and principles, and theory, beyond what may seem to be realized.

One of the modern practical subjects, that of electricity, was referred to very strongly by Prof. Burr, who showed that there is a seeking after scientific men. There was no department of engineering that employed constantly more trained engineers and who depend upon them more than that of electricity, one of the latest applications of scientific principles, and the demand comes at a time when the men can be secured to carry it on. The speaker thought we came far short in some of these things of attaining the height to which we should aim in our institutions.

One subject had struck him with a great deal of force, and he wished to add his testimony in regard to it and that was in regard to examinations. He was not aware so many did as he was doing. In all subjects where it could be done, he allowed the students to bring in their text books, and then he assigned questions that were not answered in the text books, thus throwing them upon their own resources. He also took little or no account of errors in arithmetic or algebra, but if they erred on one principle, they were conditioned, they could not pass, and would have to take another examination. He had often been surprised, after drilling a class and supposing they had a good knowledge of the subject and that only the shiftless and indolent ones would fail, he had been surprised to find frequently that one-half of the class would fail on such questions as were given. He returned all the papers to them. and if they found that he had erred in judgment, they would be allowed to pass to another subject. They did not pass necessarily on marks of fifty, or sixty, or seventy, or eighty, but they passed on the correctness of the principles, or not at all. The method had recommended itself to him very strongly. He was glad to add his testimony to its good effect upon the young men. Take the subject of resistance of beams. The amount of study which he had secured on that subject by this process exceeded anything that he believed possible in any other way. They did not know what was coming, only that they were to have an examination, and they would study all sorts of conditions and all sorts of beams, and he would give them an average question, and then find that a great many would fail. The young men that had failed once usually got through all right another time, so that it was a good exercise, provided it was done so that they got a better knowledge of the entire subject than they had before.

Professor William H. Burr said, in closing the discussion, that he would say one word, not in answer to any criticism of the paper which he had had the privilege to read, but to add another word in reference to the matter of lectures or lecture notes. It had seemed to him, in his experience as an instructor, that one of the main difficulties with the lecture system was the fact that it entailed upon the students an immense amount of unproductive work. He thought that it was practically impossible for a student to follow a lecturer in his notes and follow him in his reasoning at the same time, and he thought for that reason, that the general principles—which always remain the same, however varied their applications might be—should be taught from text books. He knew applications might be very profitably put before students in the shape of lecture notes and then the lecturer could follow in his detailed explanation of some difficult points and of the detailed applications to living engineering questions. He did not believe that it was feasible to properly do without lectures. He thought lectures perform a very important function in engineering education, but he would make them a part only, and use them in connection with text books, or rough notes which have already been prepared, so that the greatest possible amount of instruction may be given to the student with the least possible amount of uninterrupted work.

THE GROWTH OF AMERICAN MINING SCHOOLS AND THEIR RELATION TO THE MINING INDUSTRY.

BY SAMUEL B. CHRISTY, PROFESSOR OF MINING AND METALLURGY, UNIVERSITY OF CALIFORNIA, BERKELEY, CAL.

[Read in Joint Session of the Mining, Metallurgical, and Educational Sections.]

Columbia College has the honor of founding the first well organized School of Mines in America. The University of Michigan, however, shared with her the honor of graduating the first class, in 1867. Prof. Thomas Egleston was the pioneer in the new movement. He drew up the original plan for the Columbia School of Mines in 1863, and was in 1864 appointed its first professor.

The Massachusetts Institute of Technology turned out a class of mining students a year later, and others followed in the order of their first graduating class, as shown in Table I. condensed from the *Engineering News*, of August 11, 1892.

Besides the above, mining schools have been organized in the States of Arizona and Nevada, and more or less instruction is advertised in connection with other engineering schools.

It will be noticed that Columbia easily heads the list with reference to the number of graduates; the Massachusetts Institute of Technology stands second; the California University, third, and then follow Lehigh, Washington University, Michigan University, Lafayette College, Michigan Mining School, Missouri, Colorado and others.

TABLE I.

*Total Number of Graduates from Mining Schools in the United States**

Date.	School.	No. Grads. to 1892.	Average per year.
1867	Columbia School of Mines	402	15.46
1867	Michigan University	41	1.57
1868	Massachusetts Institute of Technology	126	5.04
1869	Washington and Lee (none since 1875)	8	0.03
1871	Lehigh University	48	2.28
1871	Lafayette College	40	1.71
1874	Missouri University†	26	1.31
1874	Washington University, St. Louis	43	2.26
1877	California University	55	3.44
1878	Illinois University	6	0.40
1879	Wisconsin University	12	0.92
1882	Colorado School of Mines	26	2.60
1888	Michigan Mining School, Houghton‡	27	5.40
1890	Alabama Polytechnic	4	1.33
1891	Montana School of Mines	6	3.00
1892	Pennsylvania University	1	1.00
	Total in 26 years	871	33.05

*It is to be understood that this list includes the graduates from the mining courses only, as the total list of graduates from most of the institutions named is many times these numbers.

†This institution, up to 1891, graduated its students on a three years' course. It now requires four years.

‡This institution has graduated its students: first, on a two, then on a three years' course. It now announces a four years' course. The rest all require four years, though some have unsuccessfully attempted to require five-year courses.

The total number of graduates from these sixteen schools, in twenty-six years, has been 871, or an average of thirty-three per year; but as all these schools give a partial education to many who do not graduate, it is probable that from 2,000 to 3,000 mining students have received from them considerable training.

An interesting comparison of the rate of growth of the engineering schools has been recently instituted by the *Engineering News*, for the period between 1860 and 1892.

Table II shows that civil engineering had the advantage in numbers from the start, which was maintained until 1890, when it was surpassed by mechanical engineering. The development of the latter course may be said to date from 1880.

There are many interesting facts evident in this table. It will be noticed that the curves all show inflection points in the same years. The minimum points, traced back four years, show that the year in which the minimum of graduates entered was in each case a period of profound financial depression.

But the two most remarkable points are the enormous development of mechanical engineering since 1880, and the lack of growth of mining engineering for the same period. Thus the number of graduates from all the engineering schools was:

	Mining Engineering.	Mechanical Engineering.	Civil Engineering.
1880...	37	41	157
1892...............	48	445	371
Increase......	1.3 times.	10.8 times.	2.2 times.

TABLE II.

Diagram showing number of graduates from Civil, Mechanical, and Mining engineering schools of the United States for each year since 1880.—From *Engineering News;* also:

Total Metallic product U. S., 1880–1892.

Total Mineral product U. S., 1880–1892.

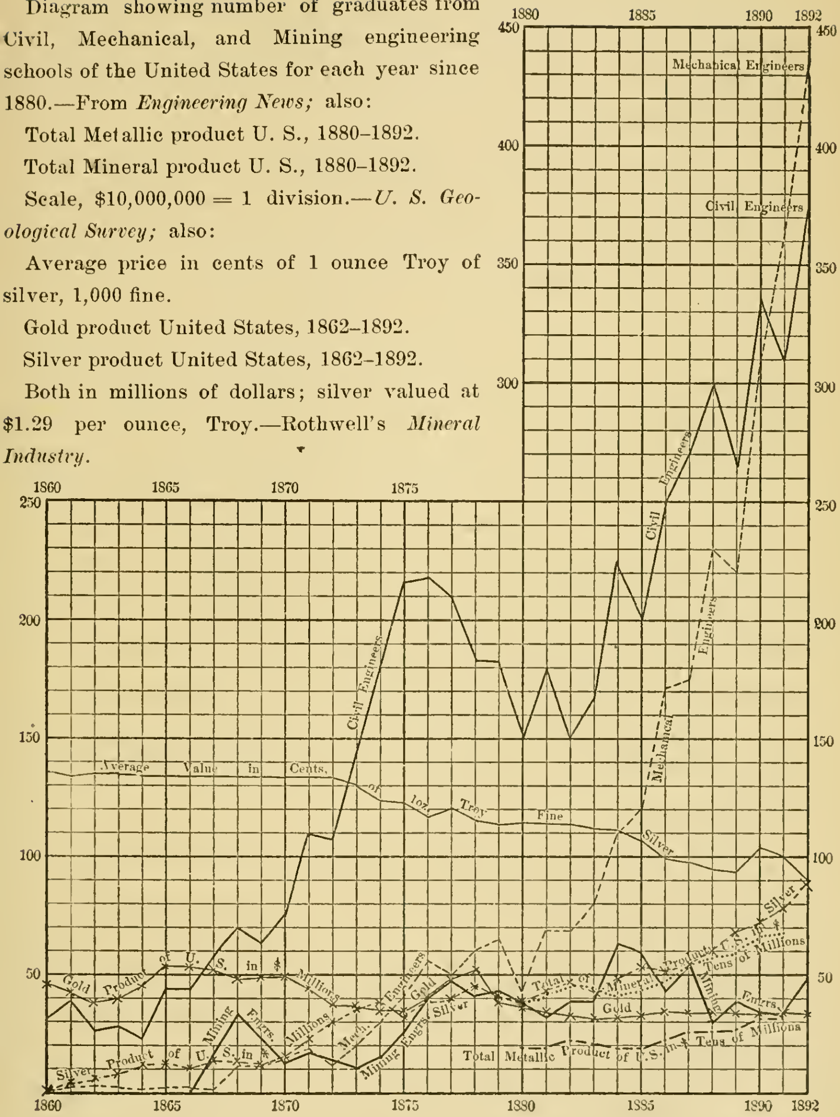
Scale, \$10,000,000 = 1 division.—*U. S. Geological Survey;* also:

Average price in cents of 1 ounce Troy of silver, 1,000 fine.

Gold product United States, 1862–1892.

Silver product United States, 1862–1892.

Both in millions of dollars; silver valued at \$1.29 per ounce, Troy.—Rothwell's *Mineral Industry.*



The questions naturally suggest themselves: What are the causes of these great differences of growth? Are the mining schools doing their duty? Is their rate of growth proportioned to that of the mining industry?

The last question is easily answered. According to the latest returns from Major J. W. Powell, director of the United States Geological Survey, the mineral product of the United States was as follows:

	1880.	1891.	Increase.*
Non-metallic mineral products...	$173,279,135	$356,216,615	2.06 times.
Metallic product...	190,039,865	302,307,922	1.60 “
Est'd value unspecified products.	6,000,000	10,000,000	1.66 “
Total....	$369,319,000	$668,524,537	1.81 times.

It is remarkable that the increase (1.3 times) in the number of graduates from the mining schools should be so close to the increase (1.81 times) in the total value of the annual mineral product of the country for the corresponding decade. In fact, no one would have ventured to predict such a close agreement beforehand.

It will be noticed that the rapid growth in mechanical engineering schools since 1880 corresponds almost exactly with the advent of electricity as a practically useful form of energy. No one can safely predict the outcome in this direction, but a reaction is not unlikely to ensue, and many young men with great expectations may meet with disappointment.

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* An outline of part of this statistical inquiry was published by the writer in the *Engineering and Mining Journal*, but it has been revised and enlarged for this paper.

WHAT IS THE NORMAL RELATIVE DEMAND FOR ENGINEERS IN THE UNITED STATES?

This ought to be a question easily answered by a direct appeal to our census statistics. The writer applied to the officers of the eleventh census, but they reported the "personal statistics" to be still in an unfinished condition, as they are the last to be worked up. In this emergency he turned to the tenth census (1880) for the actual distribution of the wage-earning occupations of the entire country. The results of this census are as follows:

Agriculture,	7,670,493	44.10	per cent.
Professional and personal.	4,074,238	23.43	"
Trade and transport,	1,810,256	10.41	"
Manufactures, mechanics and mining,	3,837,112	22.06	"
Total,	17,392,099	100.00	"

The total number of persons engaged in the mining industry is nowhere clearly stated in this census. It gives the total number of "engineers (civil)" as 8,261, and takes no account whatever of either mining or mechanical engineers, as such. It gives, as the total number of "officials connected with manufactures and mining," 8,198. To get an estimate (if anything in excess), we assume that 4,000 are in each case connected with mining, and we have, as near as may be learned from this report, the following results:

Engineers, surveyors, etc. (probably in excess),.	4,000	
Other mining officials " " . .	4,000	
Chemists, assayers, metallurgists, etc.,.....	1,969	9,969
Stamp-mill operatives,..	1,449	
Miners,....................................	234,238	
Quarrymen, ...	15,169	
Iron and steel-smelters,.................	55,649	306,505
Grand total for the United States, ...		316,474

This makes those engage in mining and metallurgy, 316,474, in a population of 50,000,000, or a total of 17,392,099 wage-earners; those engaged in the mining industry aggregate only 1.82 per cent.; or of the total population in 1880, the miners aggregated only 0.63 per cent.

The wage-earning population at this period was, therefore, distributed as follows:

	Per cent.
Agriculture,....................................	44.10
Professional and personal....	23.43
Trade and transport,...........	10.41
Manufactures and mechanics,..	20.24
Mining and metallurgy,......	1.82
	100 00

Now, although some employment is given to engineers by the first two classes of wage-earners, most of it comes from the three latter classes, each of which is closely related to some one particular class of engineering work. Thus, the work of the mining engineer comes from the activity of those engaged in mining and metallurgy; that of the civil engineer chiefly from those engaged in trade and transport; that of the mechanical engineer from those engaged in manufactures and mechanics. The personnel of these industries, we have seen, were related numerically in the ratio of 1.82:10.41:20.24, or as 1:5.72:11.12. *Hence it would seem in a general way as if the relative field for mining, civil, and mechanical engineers in 1880 was roughly in proportion to the numbers* 1, 6, and 11.*

Now, we have found the number of graduates from the schools of mining, civil, and mechanical engineering, in 1880, were in the proportion of 1:4.25:1.11; and both civil and mechanical graduates, but especially the latter, were at that time much below their normal ratio.

If we examine the ratios of graduates in 1892 from the schools of mining, civil, and mechanical engineering, we find them greatly altered; they have become 1:7.73:9.27. In short, then, unless the relative proportions of the wage-earning classes have essentially altered in the last thirteen years since this census was taken, the supply of civil engineers has most nearly approached the limit of demand, and that of mechanical engineers is still somewhat below it.

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* Employment for civil engineers comes partly from the occasional necessities of agriculture, and partly from the constant needs of municipal work. These would increase the estimate made above for the field of civil engineers. But agriculture calls only for infrequent land surveys, while municipal work occupies the mechanical even more than the civil engineer; trade alone, as apart from transport, gives very little direct employment to civil engineers—so that on the whole the writer believes the above estimate is very near the truth.

It will not do to push such reasoning too far, but it must now appear evident that the apparently abnormal growth of the schools of engineering has been in reality only a readjustment to make good an abnormal deficiency in the supply of mechanical engineers.

WHAT IS THE NORMAL DEMAND FOR MINING ENGINEERS IN THE UNITED STATES?

This question reaches to the root of the matter. For graduates of mining schools can hardly be expected to take a long, difficult, and expensive engineering course to prepare for the manual labor of the miner, for which, indeed, such training is unnecessary. They must have in view, ultimately, the position of manager, superintendent, engineer, or chemist for some mining, milling, or smelting enterprise.

As we have seen, as nearly as can be learned from the tenth census, the number of such positions in the United States was certainly much less than 10,000, or less than 0.06 per cent. of all the wage-earners in the United States.

In order to get an idea of the demand for such men compared with the number engaged in the "learned professions," the following statistics are at least suggestive:

PER CENT. TOTAL WAGE-EARNERS IN THE UNITED STATES.

Clergyman (10th census),*	64,698	or	0.37
Lawyers (10th census),*	64,137	or	0.368
Physicians and surgeons,	85,671	or	0.493
For the three learned professions,	214,506	or	1.231

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* It is a curious fact that in 1880 for every saloon-keeper in the United States there were 1 clergyman, 1 lawyer, and 1 1-3 physicians.

This number, all presumably college-bred men, is more than 21 times as great as the total outside estimate of the mining officials of the United States, and almost as great as all the miners in the country put together.

In order, however, to run this matter down to the end of his material, the writer has compiled from the volume recently issued by the eleventh census on "Mineral Industries," the statistics for the year 1889, shown in Table III.

If we make the additions suggested in the footnote to Table III for the pig-iron industry, we shall have, as our estimate for 1889:

Office,	7,683
Foremen,	17,828
Administration,	25,511
Mechanics,	45,217
Miners,	242,297
Laborers,	202,037
Boys,	30,930
Pig-iron operatives (not steel),	53,000
Total engaged in mineral industries (1889)	598,992

It will be noted that the number of persons engaged in the industry has increased 1.88 times as compared with what it was in 1879–80, while the value of the mineral product has increased 1.78 times in the same period.

We are now in a position to make a much closer estimate of the entire number of mining and metallurgical engineers in the United States. Of the total 25,511 estimated as engaged in the administrative staff of the mineral industries, it must be plain that more than half were engaged in superintending the work of

TABLE III.—*Personnel of the U. S. Mineral Industry.*

(Compiled from the Eleventh Census "Mineral Industries.")

	Office.	Foremen.	Mechanics	Miners.	Laborers.	Boys.	TOTALS.	
Coal	2,936	a 2,285 b 2,859	8,603	 158,060	38,413 58,771	17,836 9,796	299,559	
Stone	1,086	3,590	12,017	40,386	23,814	1,481	82,374	
Gold and silver	873	a 1,585 b 1,352	3,273	 29,144	17,085 3,870	82 43	57,307	
Iron*	520	a 680 b 686	2,079	 12,432	14,531 6,479	709 111	38,227	
Copper-mining	70	a 84 b 114	741 †4,236	....	1,718 1,725	20 83	8,791	13,655
Copper-smelting	77	193	613	. .. ...	3,865	116	4,864	
Lead-zinc mining	14	109	173	1,122	1,753	74	3,245	
Lead-smelting	249	173	354	....	5,595	9	6,380	12,410
Zinc-smelting	95	82	457	... .	2,024	127	2,785	
Quicksilver	20	....	....	527	434	....	981	
Tin	?	a 11 b 6	63	 141	91 10	....	322	
Nickel	6	a 2 b 2	16	 33	85 33	10	187	
Aluminum	?	?	?	?	?	?		
Manganese	....	....	....	....	432†	....	432	
Chromium	....	....	....	....	30†	... .	30	
Antimony	....	a 2 b 1	....	 12	5 8	....	28	
Petroleum	173	1,354	11,084	....	9,772	156	22,539	
Natural gas	411	374	889	....	5,004	6	6,684	
Asphalt	2	8	2	11	113	....	136	
Gems	....	....	187	....	....	112	299	
Phosphates	....	110	130	....	4,680	91	5,011	
Gypsum	....	a 35 b 11	84	 67	460 97	7	761	
Infusorial earth	....	3	4	....	45	....	52	
Corundum	....	7	5	66	51	....	129	
Millstones	. ...	3	42	....	51	2	98	
Whetstones	....	13	1	....	68	9	91	
Mica	....	15	7	95	68	....	185	
Asbestos	1	2	....	2	7	....	12	
Graphite	....	6	13	14	68	....	101	
Soapstone	....	20	71	....	177	12	280	
Barytes	....	11	7	85	107	5	215	
Ocher	....	17	14	....	162	3	196	
Metallic paint	8	10	27	....	151	3	199	
Fluor-spar	....	4	8	18	69	2	101	
Sulphur	....	2	....	7	....	3	12	
Pyrites	....	7	17	75	116	22	237	
Add for omissions(est)	142‡	....	....	....	. ...	....	142‡	
	6,683	15,828	45,217	242,297	262,037	30,930	542,992	

*See foot of next page for notes referred to in this table.

mechanics or laborers, or in clerical capacities. This would leave in round numbers about 12,000 officials connected with the actual work of mining and smelting. To those familiar with mining work it must be evident that not more than half of these would find the technical instruction of an engineering school necessary to the proper performance of his duties.

In short, we may conclude that the entire mineral industry of the United States gives employment to not over 6,000 persons who may be said to require technical training as engineers.

As corroborative of this estimate, the membership of the American Institute of Mining Engineers may be

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a. Employed "on the surface."

b. Employed "underground."

* This estimate, taken from the admirable article of Ex-President, John Birkinbine, is confined to *iron-ores,* and does not take into account those engaged in smelting the ores or producing iron and steel from them. In the absence of definite returns it is difficult to make an accurate estimate. If, however, we confine ourselves strictly to the production of *pig-iron* only (assuming the production of Bessemer and other kinds of steel production to come under the head of manufacturing, and the increase of *personnel* to be in proportion to the increase in production), we shall have in round nembers to add perhaps 56,000 men, of which perhaps 1,000 ought to be included under the head of the "office," and 2,000 as foremen.

† These may appear to have been entered in the report as *mechanics* or *laborers,* when they should have been entered as *miners.*

‡ Where no returns have been made for the "office," one-half the number returned as foremen has been taken.

NOTE.—The absolute accuracy of these census statistics is not to be assumed. The mineral statistics are particularly difficult of attainment and are naturally likely to be underestimated. On the other hand, in the cited. The liberal basis on which membership of this society is founded insures for it, as compared with similar societies, a large proportionate membership of those interested. In 1891 it had a membership of 2,092. This is one-third of the number estimated above.

THE ANNUAL OPENINGS FOR GRADUATES OF AMERICAN MINING SCHOOLS.

A young man can hardly be said to be fitted for a position of technical responsibility before the age of twenty-five years. Let us suppose he enters the

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eleventh census men, were employed to collect the mineral statistics who were usually well fitted for the task, being in most cases really noted specialists in particular lines.

Regarding gold and silver, the writer quotes from R. P. Rothwell's able article:

"The number of gold and silver mining 'claims' or 'locations,' commonly called 'mines' in the United States is practically beyond computation. The names of nearly 100.000 of such claims or mines were received by the census office, but upon limiting the investigation to: (1) producing mines, (2) working but not producing, (3) mines temporarily stopped, but which had produced or upon which the work done had established their value, and which could properly be classed as mines, the list declined to perhaps 10,000, and upon tabulating only such mines as made returns of production or labor statistics, the list was reduced to 6,004, which is still a large number compared with the other mineral-producing mines in the United States."

Attention is called to these facts and to the extreme difficulty of including all engaged in this industry; for it is not unlikely that instead of 57,307 men engaged in this business, it may have occupied 100,000. The product was in round numbers $100,000,000, of which one-third was gold, and two-thirds silver.

Table III, which has never been in print before, is worthy of considerable study; there are many important conclusions that may be drawn from it, but these would unduly extend the present paper.

technical school at eighteen, graduates at twenty-two and serves a practical apprenticeship as workman or subordinate for three years; this supposition will agree fairly well with the usual practice.

At the age of twenty-five, the average remaining life of a man is estimated at thirty-eight years. If, now, we assume an average working life of thirty years, it must be plain that to keep up the supply of 6,000 engineers, there will be required 200 new men each year.

It is evident, therefore, that the supply of graduates turned out by the mining schools in 1892, namely, forty-eight, is not so extremely out of proportion to the demand as at first sight appeared.

We must remember that most of the mining schools partly train for two to three times the number who graduate, and that the graduates from foreign mining schools also compete for places. These considerations are partly offset by the fact that all who graduate do not need or choose to follow their profession, and that some practice it abroad.

Making these offsetting allowances, it would appear that there are about four times as many openings as there are mining graduates to fill them. This is a condition of things which agrees very well with experience, and shows why there is such a steady demand for the graduates of the best mining schools.

They are reasonably sure of good and remunerative positions if, in addition to the proper training and experience, they have the peculiar natural faculties essential for success in any branch of engineering.

It must be evident to any candid mind that adverse criticise of American mining schools, founded on the small number of their graduates, is without substantial foundation.

ARE MINING SCHOOLS JUSTIFIED?

This question can hardly fail to suggest itself. If the mining population be so insignificant in numbers; if there be only a couple of hundred mining engineers required a year, why should we maintain expensive mining schools?

The answer, on a mere commercial basis, is not far to reach. *The miners may be insignificant in numbers, but in respect of the value produced as a result of their labor, they are the most important element in the entire population.*

Thus, in 1880 the actual money value produced as the result of labor, per capita, was as follows:

Agricultural	$ 289.00
Manufactures (gross value, less one-third for raw materials),	996.00
Mining industries (all engaged)	1167.00
Miners only	1577.00

The statistics for the year 1889 for agriculture and manufactures are not yet at hand, but those for mining are:

Actual value produced by all engaged in the industry per capita,	$ 981
Per miner only engaged	2,900
Per administrative officer	23,920
Per estimated engineer	98,872

If it be true that "money talks," this showing should be a sufficient answer.

If each captain of the mining industry actually superintends and controls an average production of nearly $100,000 a year, is it not important to the nation that they should be thoroughly trained to their business? The community has a right to demand that into their training shall go all that modern science can give to make them efficient.

Surely it is not a bad investment to spend a thousand dollars a year in educating a man for four or five years who shall have the direct control of the production of $100,000 a year for thirty years! The sum total is an average of $3,000,000 as the result of the work directed by each mining engineer in the United States during his working life.

When we come to consider, not the gross output, but the net profit, these conclusions are even more strongly enforced. And when we consider the peculiar nature of mineral wealth, the value of such a policy to the nation is even more apparent.

The farmer can harvest his crop year after year; most of his increase comes from sun and air and rain; he has only to fertilize the soil now and then, and his farm remains a source of wealth from generation to generation.

But there are no fertilizers for worked-out mines. The crops the miner reaps can be harvested but once, and what he leaves behind through lack of skill is forever lost.

It is now plain why a large mining company is often justified in paying an experienced mining engineer from six to twenty-five thousand dollars a year. Such a man is often able to earn for his employers many times his salary. And it is also evident that the field for mining engineers, though limited, holds rich rewards for those who have the training, the experience, and the energy for such responsibilities. It is a field where inefficiency and weakness of body, mind, or character are signal disqualifications.

ATTENDANCE AT AMERICAN AND EUROPEAN MINING SCHOOLS.

A complete comparison of this sort is difficult to make, because it is not easy to obtain the data for all of these schools at the same period, unless we select a date somewhat remote; and because in Europe it is the custom to distinguish between schools for engineers *(Bergakadamien)* and for miners *(Bergschulen)*. The following are condensed partly from Professor R. H. Richards' admirable paper on "American Mining Schools," *Trans.*, vol. xv., pp. 814, 816, etc., and partly from other sources mentioned below.

The first striking fact which this table shows is the small number of students of mining engineering in the famous Royal School of Mines at London. In the period from 1851 to 1890 this school has graduated in mining, metallurgy, or geology, 303 associates; of these, twenty-seven were in geology only, which leaves for mining and metallurgy 276, or an average of seven per year.

The other English schools might swell the list somewhat, but it is evident that the number of mining students in England is small in comparison with the English mining interests.

On the continent, where mines and mining are largely under government control, we should expect to find a very different state of affairs; but even in Germany, the birthplace of scientfic mining, her four great mining schools contain only 406 students, while Austria has 117, France less than 200, and Sweden, with her famous iron industries, only seventeen.

TABLE IV.

Attendance at Mining Schools for 1887.

AMERICAN.		EUROPEAN.		
Columbia	87	*England*—Royal School of Mines		60*
Lehigh	68	*Saxony*—Freiberg		163
Massachusetts Inst. Tech	30	*Prussia*—Aachen	43	243
California	23	Berlin	104†	
Pennsylvania	17	Clausthal	96†	
Ohio	14	*Austria*—Leoben	29‡	117
Lafayette	12	Klagenfurt	8	
Michigan	8	Mahrisch-Ostrau	23	
Washington	7	Dux	17	
Illinois	3	Prizbram	40	
Wisconsin	3	*Sweden*—Stockolm		17
Total	272	*France*—Ecole des Mines de Paris	111	191
		Ecole des Mines, St. Etienne	80	
		Belgium—Liege		—
		Total		791

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* This estimate for students in the Royal School of Mines proper, for 1887, is made by an associate of this school. There were several other schools in England giving some instruction in mining, but this seems to have been at this time the only one with a regular course for mining students.

† *Preussische Zeitschrift fur Berg-Hutten-und Salinenwesen,* Bd. 38, S. 378 B.

‡ *Oesterreichishe Zeitschrift fur Berg-und Huttenwesen,* 1889, Bd. 37, S. 224.

Omitting Belgium, for which I have no data, it is plain that the United States had more mining students than any country in Europe except Germany, and that she had more than one-third as many students in her mining schools as Austria, England, France, Germany, and Sweden together.

It must be evident that the attendance at mining schools, the world over, is extremely small compared with that of the schools of law, medicine, and theology. Thus the attendance at the Berlin Mining School *(Bergakadamie)* for 1887 was 104, while at the Berlin Institute of Technology *(Technische Hochschule)* it was over 1,100, and at the Berlin University over 5,000.

But it would be a great mistake to conclude from their small numbers that these schools were unimportant. In collecting materials for this paper, the writer happened on a list of the seventy-six Americans who studied at Freiberg between 1819 and 1865. The names of twenty-five of these have become familiar as household words to all members of the mining profession in America. They have become leaders in nearly every branch of mining and metallurgical enterprise. The industries of coal and iron and steel, of copper and lead, and gold and silver, are all debtors to these old-time students of Freiberg.

The mining schools of Paris, Berlin, and London have educated many brilliant American engineers, and if the influence of these mining schools could be blotted out from American mining practice, it is safe to say that the record of which we are so proud to-day would never have been made.

DIFFICULTIES PECULIAR TO THE AMERICAN MINING SCHOOLS.

In Germany and Austria the mines are largely under government control, and are worked, not so much for immediate results, as to get the greatest ultimate yield. In America they are exclusively under private control.

The American system has many distinct advantages, particularly in a new country. Routine and precedent are thrust aside, and energy and originality have full sweep. But it must be admitted that there are serious drawbacks to this system. Not infrequently mines are owned and controlled by persons without the slightest technical knowledge, and often by those interested more in the speculative than the productive value of the property; and in such cases a thoroughly trained mining engineer is not a desirable superintendent. Any man who will work the mine for the market will do better.

This policy, which often enriches the speculator in a fabulous manner, leads the public to think that a long course of training is unnecessary to the mining engineer, because the most successful operators in this kind of "mining" have been without it. The failures which overtake most men of this class are seldom noticed, as in a lottery one success hides a hundred failures.

As a single comparison: the Idria mine in Austria was discovered almost in the same year that Columbus discovered America. It has been in almost continuous operation ever since. Every resource known to science has been tried, to ensure the greatest ultimate yield. For over four hundred years it has given employment to generation after generation of miners, and has yielded a small but steady income on the outlay.

Compare with this record the history of the Comstock lode. If the Idria mine had been in America it would have been "worked out" in twenty-five years, and have produced, perhaps, two or three millionaires. Which system is in the long run better for a country, it is not hard to decide.

If a government is ever justified in controlling the business affairs of its people, surely the mineral wealth of a country, and the conditions under which it should be removed, are the ones which most need regulation and control. Nevertheless, in the present condition of our civil service, such a change would only add to the difficulties and dangers of our government, and may be dismissed as impracticable.

But the bearing of the above facts on the engineering schools is evident. On the continent of Europe the only road to success lies through the mining school; in America there are many "short cuts," and the man who takes them learns his mistake too late to profit by it himself, and is often too proud to admit it by warning others.

Again, the work of the mining engineer always involves more unknown and indeterminate quantities than in any other branch of engineering. Moreover, it is more remote from business and money-centers; it seldom receives the same intelligent and appreciative criticism that awaits the work of the civil and mechanical engineer. Their work is always in the eye of the public. His is hundreds of feet below daylight, and hundreds of miles from the public centers. In the best case, mine owners are forced to estimate the capacity of their engineer or superintendent, not from the difficulties he overcomes, but from the dividends he produces.

Nevertheless, as the more easily worked mines are exhausted, it is certain that the value of technical training will in the future of American mining practice become more and more recognized. No one can deny that American mining is carried on with an energy and force which is the admiration of the world. But perhaps none would more readily admit the need for better scientific and technical training, than those to whom we are most indebted for the advances we have made; for none are better aware of the enormous waste that results when ignorance and incompetence are at the head of affairs.

But mining schools labor under another difficulty that other engineering schools do not have to meet. The miners, their peculiar constituency, are scattered over the most remote and inaccessible quarters of the globe. Other schools may draw their best materials from the densely populated centers in which they are placed. But much of the best material for the mining schools is obtained from among the sons of the miners themselves. Now the situation is this: these young men, except in rare instances, are utterly unable to acquire more than the merest elements of a general education. The requirements for entrance to an engineering school are in such cases as absolutely beyond their reach as if they were the inhabitants of another planet. Some attempts have been made to move the schools to the mining centers. More students may be at first secured from among the miners, but it is necessary for the schools to give them elementary instruction several years before they can properly be called engineering students. There would also need to be an engineering school for each mining center, which is impossible. This solution of the difficulty is therefore more apparent than real.

Most schools attempt a partial solution of the problem by admitting men from the mining regions as "special students" to such classes as they are fitted to enter. Most of them confine themseves to such studies as can be pursued without mathematics, so that few of them are fianlly able to graduate, but these few who take the whole course attain success of a high order. To reach and help this class of material is, in the writer's opinion, the real problem of the mining schools.

On the continent of Europe, where the mines are largely under government control, this lack of provision for the lower mining education does not exist. Thus, in Prussia in 1889 there were at the mines ten *Bergschulen*, with 408 students, and twenty-nine *Berg-Vorschulen*, with 482 students, for foreman and workmen respectively. A similiar practice holds in Austria and France. Under American conditions such a solution of the difficulty seems impossible. Nevertheless, a remedy may not be entirely out of reach.

An interesting enterprise has been recently attempted by the *Colliery Engineer*, of Scranton, Pa. It is called the "Correspondence School of Mines." This school claims to have 1700 pupils. It claims to teach by the method of correspondence for its "Full Scholarship" of $50, "*to any who knows how to read and write*," the following subjects: "1. Arithmetic; 2. Ventilation; 3. Geology; 4. Search for Coal and other Minerals; 5. Modes of Working; 6. Surveying and Mapping; 7. Mechanics; 8. Mechanical Drawing; 9. Ambulance; 10. Mine Legislation; 11. Mine Accounts; 12. Blowpiping; 13. Mineralogy; 14. Assaying; 15. Economic Geology; 16. Prospecting."—*Circular of* 1893, pp. 16, 22. "The Full Scholarship will take a quick student, *who can only devote his time after working hours to study, twenty-four months. If the student knows nothing of Arithmetic when he commences, it will take longer.*" *Ibid.*, p. 46. "*Algebra is not used*," p. 15. [The italics are mine.]

When it is considered that the usual mining school occupies its students an equivalent of ten hours a day, nine months in the year for four years, and that they are already familiar with arithmetic, algebra, geometry and much more to begin with, it may be seriously doubted whether (with the working miner) all this ambitious programme can be fulfilled to the letter. It must be evident that such an undertaking cannot train mining engineers, and apparently makes no such pretensions.

Nevertheless, it seems that the method here indicated is almost the only one which can reach small outlying groups of miners. The fact that one thousand seven hundred persons, many of them evidently working miners, have enrolled themselves, shows that a need is felt among them for some instruction.

If now, instead of offering "diplomas" for the course advertised, it was modified so as to correspond more to the entrance requirements of our best mining schools; and it could be shown that such a course would enable a young man at a mine to prepare himself for the full course in the best mining schools, a most important advance would be made.

It is evident that there is no justification for a school for miners unless it can teach them something they need to know, and which they cannot learn at the mine. Besides the ordinary English branches, such a course might include arithmetic, bookkeeping, geometry, algebra, trigonometry, elements of physics, chemistry, and mineralogy, the two latter taught largely by means of the blowpipe. The problems and illustrations might be drawn almost entirely from mining practice, and the course would be equally useful to a miner, whether he afterwards wished to attend a school for mining engineering or not.

If some such plan as this could be carried into effect, it would help to bridge the gap between the miner and the mining school, and would make available for mining engineers some of the best material in the country.

THE FUTURE OF AMERICAN MINING SCHOOLS.

Since the memorable address of the lamented Holley, in 1876, on the "Inadequate Union of Engineering Science and Art," the conditions have changed in all our engineering schools, and in none more than in those for mining engineers. These changes have resulted mainly from the initiative taken from the Columbia School of Mines and the Massachusetts Institute of Technology. Alive to the difficulties of the situation, Professor Robert H. Richards and his colleagues at the Institute devised, organized, equipped and first perfected the so-called "Mining Laboratory." This is in reality a working laboratory in the college, where problems in ore-dressing and metallurgy may be worked out by the student, as Professor Roberts-Austen well says, "Very nearly on a scale of twelve inches to the foot." Its utility is everywhere acknowledged, and it may be said to be an essential part of the typical American mining school. The contribution of Columbia School of Mines is largely due to the foresight and energy of Professor Henry S. Munroe, who first organized and made effective, as a means of systematic instruction, the "Summer School of Practical Mining," from what had hitherto been a mere summer jaunt without definite plan or purpose.

It seems to the writer that these two independent solutions of the difficulty are equally indispensible. The one enables theory and practice to blend during the school year; the other forces the student during his vacations to realize the working conditions he must meet after he graduates, and enables him to adjust himself to them before he makes the final plunge. Taken together, these methods make the continuous blending of engineering science and art for which Holley made his eloquent appeal. These new methods have had a most admirable effect, not only on the student, but upon the professor and upon the school. They keep all in touch with the working miner and his needs.

In the summer school lies the best method of bridging over the gap existing between the man practiced in the school and the man schooled in practice. Between them there is always a lack of sympathy, and, on the part of the latter, often a latent distrust, if not active jealousy. But they must work together in harmony to produce results. There is no way to understand the miner like that which comes from doing his work and sweating under his burdens, and the engineer who expects too little or too much of his subordinates seldom accomplishes anything.

The writer believes the summer school is capable of much greater development than it has yet received Utilized to the full, it gives the mining student, at annual intervals, four periods of nearly three months each, wherein he may attain a wide range of personal experience in surveying, field geology, mining and metallurgy, thus fitting him at once for a position of *subordinate responsibility* on graduation. Whatever may be the future of American mining schools, the mining laboratory and the summer school of practical mining will prove enduring and characteristic features.

A peculiarity of the American mining schools, as well as of American universities seem to be an over ambition to provide for the higher branches of education, together with a lack of adequate provision for the lower preparatory branches. Now, if there be a demand for two hundred mining engineers a year, there must be a need for double the number of mine foremen. To graduate two hundred engineers a year would necessitate perhaps one thousand students. This number could be taught by ten or even better by half-a-dozen, schools. Schools of mining engineering are expensive; two million dollars is a minimum endowment to make such an engineering school really effective, and three would be better; while many elementary schools of great usefulness to miners could be established for much less.*

There are now perhaps twenty more-or-less endowed mining schools in America. It would be a distinct gain if the field could be sub-divided. If all having less than two million dollars endowment available for the actual needs of the mining school were to confine themselves to elementary instruction preparatory to the higher work of the other schools, two great advances would be made.

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* Two million dollars may seem a large sum, but it is easy to demonstrate that an adequate equipment and teaching staff can not be provided for less. In most cases, under American conditions, such endowments are justified only when the mining school is a part of a large and strong institution. A single national school of mines might at first sight seem justified as a measure of economy. But after a school reaches a certain size, duplication of plant and teaching force is in any case necessary, and the single school would lack not only the power of adapting itself to local needs, possessed by a half a dozen properly distributed schools, but also the advantages secured from a healthy rivalry. The latter is a factor in sound growth not to be ignored.

We should probably have perhaps half-a-dozen schools for mining engineers and twice that number for mine foremen. The mining schools of the first order might contain, together, a thousand students, and those of the second order perhaps four thousand.

The instruction of the latter might be partly by correspondence and partly personal, so that the actual needs of the miner could be met. The object of such schools should be to fit the miner for those duties as foremen, which require some scientific training. It should also fit for the engineering schools the few among them who display signs of distinguished ability.

The six schools of mining engineering thus relieved of elementary work, and with bodies of students sufficiently great in numbers to secure that *esprit de corps* so necessary to any body of professional men, would be able to devote themselves to engineering work of a high order.

In each of these schools the same course of scientific training and the same firm grasp of principles which govern engineering practice are necessary. But it is impossible for any one of them to cover in detail the whole range of engineering practice. and it is a mistake even to attempt it.

With a firm grasp of principles, the student needs to acquire that art of all arts to the engineer, the faculty of working up his details as he needs them. Such a man succeeds where cyclopædic erudition fails. Important in the training of all engineers, this faculty is vital in all mining practice. It is best acquired, not by attempting a superficial knowledge of the details of the whole art, but by actually mastering, from the bottom up, the details of a few well-chosen typical branches.

Another great saving of energy would be effected if the schools were to select for this detailed study mainly, though not always exclusively, those branches locally most important and readily studied in detail. Particularly for summer-school and laboratory work, subjects could be selected by each school from one or more of the heads named in some such list as the following:

(1) Mining and dressing of coal and iron.

(2) Metallurgy of iron and steel.

(3) Mining and smelting of cupriferous ores.

(4) Mining and smelting of silver-lead ores,

(5) Mining and smelting of zinc-lead ores.

(6) Mining and milling of gold and silver-ores.

(7) Lixivation of gold, silver, and copper-ores.

(8) Mining and metallurgy of quicksilver and the minor metals.

(9) Quarry-work.

(10) Hydraulic mining.*

The whole mining field of the country could be thus divided up among a half dozen strong mining schools, which taken together would better serve the needs of the community than any national school of mines that could be founded.

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*In making out the above list there have been grouped together things industrially related, for they are most readily studied at the same place. The first two subjects include over half the mineral workers in the United States.

Suppose that each of these schools, after a sound course in the physical sciences and the underlying principles of the art, were to concentrate the energies of its advanced students on the detailed study, at first hand, of such technical questions of local importance as were within their time and power. Fewer subjects would be covered, but more engineers would be trained. Wisely administered, this policy would not lead to narrowness. For mining engineering, is above all things, the application of science to local conditions; and the student who has once clearly set before himself an end to be reached, has met the local conditions face to face, and has mastered them, is better equipped to triumph even in a widely different field, than he who has been painfully armed at every point with precedents. Precedent may make the lawyer and the scholar, but it can not make the man of science, and least of all the engineer.

The right to confer the degree of Mining Engineer should be confined to mining schools of the first order. The degree should be given only to those students who have not only successfully completed the full course of study, but who have had at least three years of practical .experience in a position of subordinate responsibility. In short, it should be granted only to those who actually are engineers, and not, as now in many cases, to those who are only prepared to become such at the expense of their employer. The degree should be open on equal terms to self-educated men.

The right to confer the certificate of Mine Foreman should be given to the mining schools of the second order. The certificates should be given only to those who had not only passed the necessary examinations, but had had at least five, or better ten, years of experience in the actual work of the miner.

Under these conditions there could be no question as to the competence of the holders of such certificates and degrees. Such papers would possess a real value.

It is unlikely that our national government will ever assume the ownership of its mines, although our states still retain the right to prescribe, by legislation, the conditions of their safe working, as they do the sale and use of drugs and medicines. Some of our coal mining states have already required certificates of competency from mine foremen, and the sytems in vogue, though not always above criticism, have resulted in the saving of many lives. State requirements, fixing a certain standard of theoretical training and actual experience for all who practice mining engineering, would effect a large saving of lives, of capital, and of mineral wealth.

Such laws would prevent men without training from receiving positions of responsibility, and at the same time would leave great freedom of choice to the mine owner. But this is so foreign to our national tendencies that it is improbable that our mining schools will ever receive the backing that comes from the government control and onwnership of mines. Nevertheless, there is such an inherent force in earnest convictions that even without it much may be accomplished by the co-operation of those who think and feel alike. The brilliant success of the American Institute of Mining Engineers is an example of what may be accomplished by private action. No law holds it together, yet few governments have done more to elevate the profession than this society. If half a dozen of the most active of our mining schools were to take common ground on some of these questions, and were to receive the hearty backing of the leading mining engineers and mine owners of the country, much could be done to establish, in fact, the bond of union between the mine and the mining school which in America does not exist in law.

As the writer has called special attention to the comparatively small number engaged in the mining industry, he cannot close this paper without one word more as to the importance of the miner to the nation. Less than two per cent. of all the wage earners in the country are engaged in the mineral industry, but fully eighty per cent. of all of them are directly dependent for their livelihood on either the production or the consumption of the miner.

Agriculture and mining are the only fundamental arts. Without agriculture, existence would be precarious; without mining, civilization impossible. Wood might indeed replace coal; but without iron and steel, without copper and lead, the locomotive, the ocean liner, the deep-sea cable and the overland wire, the press, the loom, the ploughshare and the pruning hook would melt away. Without gold and silver, commerce would stagnate, one by one our boasted arts and sciences would disappear, and the darkness of the stone age would overtake us. It is no exaggeration to claim that civilization rests upon a metallic basis.

The little army of miners is no longer insignificant. Who can withhold from its members an involuntary tribute of respect, when we view the smallness of their number, and the importance of their work; when we reflect upon the uncertainties, the hardships, the dangers which surround them; explorers of another world; sailors, who drive through seas of solid rock; soldiers, whose daily task is a battle with difficulties, danger, and sudden death—the advance guard of civilization, the salt of the earth!

THE EQUIPMENT OF ENGINEERING SCHOOLS.

(Introduction to a Discussion.)

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The equipment of an engineering school has come to be, in these later years, a vastly more important, extensive, and costly accessory to the school than was dreamed of a generation ago. The fact has come to be recognized that the school or college of engineering, like those of law and of medicine, is properly and necessarily the place and the means of training young men for a learned and exacting profession; it is no longer regarded as a boy's high school in which a feeble general education should be supplemented by still more rudimentary lessons in science, the milder sort of "higher mathematics" and a suggestion of the simplest elements of surveying, if the course be distinctively civil engineering, or of draughting and kindergarten shopwork if one of mechanical engineering. The profession of engineering has not only been established as a learned profession in the generation just passed, but it has come to exact of its novices, where trained in the most advanced and successful school, a more extended preparation, a more arduous professional course, than are demanded, to-day, by the schools of either law or medicine; and this fact, if there were no other corroboration of the conclusion, has fully established the engineer in his position as a member of a profession, and of a learned profession.

The necessity of conducting the student, already proficient in the elements of the mathematical and physical sciences, through a course of instruction that shall give him familiarity with the principles underlying every operation which, as a practitioner, he must, later, conduct or direct, compels the schools to provide themselves with all the apparatus of instruction in the physical and chemical laboratories. This was admitted and practiced years ago in the better class of engineering schools, but of late it has come to be seen that a truly professional school in this department also must be prepared to give instruction in the methods and practice, in the actual conduct, of all those operations which involve the application of scientific processes and exact measurement; in all the standard methods of determination of the value and of the distinguishing characteristics of the materials employed in construction; and in the ascertainment of the efficiency of such motors and machines as the engineer employs in professional work. This necessitates an outfit which includes, in the case of civil engineering schools, not only the instruments of surveying and field engineering, but testing machines and apparatus of the laboratory for testing materials of construction. In the case of the school of mechanical engineering, a whole series of extensive laboratories and complete workshops are required, including the mechanical laboratory for testing materials and the experimental machinery, such as steam, air, and gas engines, steam-boilers, and other costly apparatus peculiarly necessary in the instruction of an engineer whose province it is to design, to construct, to operate and to determine the value of all kinds of machinery. So extensive and so costly have become these equipments of the great engineering schools in the United States that it has come to be seen that only large capital can secure such an outfit as can now be made useful in undergraduate and in post-graduate work, and that, however large the available funds, only wisdom, experience, and the utmost care in selection can make the equipment of the best and most wealthy of these schools yield maximum returns. It is thus important to consider what principles should govern the officer in charge of this class of instruction in the planning of a proposed equipment, the selection of its elements and the employment of the whole in such a manner as shall give the largest amount of instruction at the lowest cost of annual operation. It is this problem that it is proposed here briefly to study, with the purpose mainly of inducing discussion and a comparison of views and experiences among those members of the Engineering Congress who are most interested in securing the best solution.

The nature of an equipment such as should be given an engineering school of the highest professional standing is by no means unanimously determined by either practitioners or professors. In Europe, comparatively few schools of this class have what would be considered, in this country, an equipment for professional instruction. A moderately good outfit in physics and in chemistry, for example, is all that is possessed by one of the most famous of all the schools of France. Few German schools have what we term a "mechanical laboratory, for testing materials, open to students or used in regular instruction of students in engineering. No British school has yet approached our ideal of a satisfactory outfit; although a number have secured single large testing machines and "experimental" steam-engines. One distinguished English authority and a professor in one of the most reputable of British schools of engineering explicitly declares that he does not consider such equipments as desirable. He would give the novice instruction in the mathematical and scientific principles underlying the practice of engineering construction and would then send the student into the field or into the office or the manufacturing establishment to obtain the remainder of his professional training. He would not even use a model, on the ground that the engineer deals with drawings and that the graphical representation, rather than the concrete substance, should be made familiar to him.

But it has come to be well recognized in this country, at least, and is coming to be seen abroad, as a result largely of our successful practice, that the more the young engineer is systematically and thoroughly trained in the professional as well as in the scholastic work distinctive of his field, the better engineer does he become. It is also coming to be seen that a month of this regular, scientific, systematic training in professional work, especially in the case of the young mechanical engineer, is worth more to him, is more productive of results, than years spent in the haphazard, irregular, and always more or less incomplete training of commercial establishments. In fact the exact methods of science, as taught in the best schools, can never be learned in the field or in the shops, which oftenest train the young engineer to habits of inaccuracy, shiftlessness and content with a low standard of excellence, such as are likely to ruin his future rather than give him aid in his efforts towards advancement and professional success. It may be taken as settled that the best judgment of the best authorities has been declared in favor of a material equipment for the engineering school and a very complete and extensive one. What shall it be? That is the present and the live question for us.

Speaking generally and broadly, it seems sufficiently obvious that the equipment of every engineering school should be such as will best illustrate the scientific principles taught in its elementary work and the processes of engineering practice which naturally constitute essential parts of the work of instruction in such schools and which can be better taught there than in the uncertain and unsystematic school of regular engineering practice, and such as will afford opportunity for the acquirement of familiarity by actual touch and practice with all those methods of scientific research in engineering which are now so commonly and so generally found to be essential elements of professional preparation for the practitioner, and which cannot usually be learned with any degree of accuracy, completeness and satisfaction, if indeed they can be taught at all, outside the engineering school. Above all, it may be said, in speaking of the higher schools of engineering—the professional schools without admixture of the diluting elements of extra-professional work—the equipment should comprehend all that is needed to make them capable of supporting, as graduate departments, systems of instruction in all the most advanced lines of applied science in engineering and of carrying on and promoting scientific research in fields still unfamiliar to the practitioner but in relation to which he is daily compelled by the rapid advance in professional and general practice to seek additional information, or within which unexplored fields are constantly arising problems challenging solution. Scientific investigation and research in all departments of engineering are coming to constitute the main lines of advance and the principal occupation of scientifically trained graduates of the schools pursuing advanced work. Thus that equipment is best which, within the range of the work of the school for which it is intended, gives the most complete facilities for illustrating its courses of instruction and for original research in the various lines of applied mechanical science.

Exact adaptation for the purpose may be thus assumed as the primary requisite in the establishment of an outfit for any engineering school. The courses of instruction should be first thoughtfully planned with a view to high efficiency and most perfect fitness to the object in view. Their illustration by a collection of equally well-chosen apparatus is the next and natural step of preparation for work. The last of all methods of equipping any school is one which is nevertheless sometimes observed, the collection of all sorts of apparatus and machinery, wherever or however they may be obtained, and the subsequent distortion of the courses of instruction to bring them into service. One simple, inexpensive piece of apparatus, or one bit of machinery, illustrating well an essential principle is worth more than the most imposing and costly piece of apparatus or a collection of expensive machines of which the main value is that of the museum. One thousand dollars expended in the purchase of the simple and complete series of illustrations of mechanical principles taught in the earlier part of the course of instruction in the engineering school has more intrinsic and paying value than ten thousand dollars paid for some costly, but seldom needed, instrument or machine, the elementary collection lacking.

The elementary outfit should be the first secured, and, if any difference were allowable, the most carefully chosen. It is here that a stated sum may be made to do most good. It will purchase the largest amount of useful illustrative apparatus, will render efficient the instruction of the largest number of students, and will do most, in all ways, to make the work of the school efficient. The equipment for illustration of the course of the first year should be purchased first and with most liberality of expenditure; next the outfit of the second year should be procured, then that of the third year and of the latter part of the course; and, finally, a sufficient amount of capital being available, there should be gathered together, first the simpler, and then the more ambitious portions of the equipment of the departments of experimental engineering and of research. Every principle and every method should be illustrated, where practicable, and by concrete apparatus and mechanism—by the real, *live*, machinery and apparatus of actual practice whenever possible—if it be the methods of engineering that are to be exemplified. The outfit for the elementary portion of the course is commonly easily obtained and its place and purpose are so definitely fixed by the character of the course to be illustrated that no hesitation will be felt, ordinarily, either in regard to the nature or the quantity of the illustrations. Choice of quality is often allowed, and, as a general rule, exact adaptation to its purpose is the one requisite to be insisted upon in selection. On the one hand, no defect of design or of construction should be allowed; on the other, nothing should be wasted on unnecessary polish or inappropriate and costly material. As moderate cost as is consistent with good form, material, workmanship, finish, and durability should be insured. Good judgment and deliberation in choosing precisely the right method and apparatus of illustration will usually provide all that can be advantageously employed in the elementary departments, with a moderate expenditure of capital.

The tools of trade constitute, in all engineering schools, an essential part of the equipment. They are needed not only in illustration of the principles and methods of work, but also, and mainly, for use in the practice of the art with a view to giving every student familiarity by its practice with all its essential operations. These instruments and tools should always represent the most serviceable makes, and should be excellent in design and construction, with no superfluous finish or ornamentation, and above all, thoroughly accurate. They should represent the apparatus and tools of the best practitioner, as chosen by him for utility and durability. Accuracy and reliability are the first requisites: convenience, handiness, portability, where transportable, should also be insisted upon. Where perfectly practicable, when numbers are required of the same kind, the makes of several of the best manufacturers should be included in the outfit, in order that the student may be able to observe the differences among them, their several advantages and disadvantages, and their excellencies and defects, as well as make himself familiar with their peculiarities with a view to becoming competent to use them all, whenever and wherever met with in later practice.

Such collections of tools, to be of maximum value, must be selected each with a definite purpose, accessory to the main purpose of the school, to which it should be adapted most perfectly. To this end the plan of operation of the establishment must first be exactly determined and fully planned in every detail, and the kind and quantity of every sort of tool needed should be predetermined. If the school is to be mainly a manual training school, the exercises will presumably be graded from those requiring comparatively little skill in the use of the simplest tools, to those exacting the highest skill and the use with ease, accuracy, and certainty, of the most important machines, and the concluding courses should be regular exercises giving the desired manual training, with more or less of instruction in the processes of construction and assemblage of parts and complete products. If the school be one of mechanical engineering of the highest grade, for example, and its students men of some maturity and ambition, pursuing a course of purely professional training, the shops of the school must be prepared to illustrate all the processes of the trades subsidiary to that branch of engineering, to aid instruction in every elementary principle and in all applications of woodworking, blacksmithing and tool-making, foundry work and machinist's work, that commonly contribute to the development and completion of the engineer's designs. The course to be given will have been properly planned in all details, in advance, and the outfit will be selected in such manner that every tool needed will be supplied, each in the number required to do the total work demanded of the kind for which it is specially contrived, and with the result, when the shops are in operation, of keeping every tool working constantly, and of invariably meeting every demand for the specific operation contemplated by the designer of the course and of its products. In such shops, it is usually considered desirable that the course should begin with so much of manual training, in each of the trades, as will give the novice a fair degree of familiarity with the tools, their purposes, and their use, as well as of the character of workmanship attainable or desirable—the finest workmanship is not always the best, in business — following this preliminary instruction by the more ambitious work of actual construction of one or more standard articles of manufacture. These articles are so chosen as to illustrate best the largest number of mechanical operations, while, if possible, producing a machine or other product of interest and value in itself, as seen both from the point of view of the instructor and from that of the engineer. The collection of an outfit of tools for such purposes as these evidently involves careful study, large experience, and excellent judgment. Failing these pre-requisites, large sums of money may be utterly wasted; for such equipments are very costly at best. In no direction will be found larger differences between the cost and the results of operation of well-selected and properly employed outfits on the one hand, and badly chosen and inefficiently utilized tools and machinery on the other.

An outfit for experimental engineering, both for instruction and for research, constitutes, in the larger and more advanced schools, the most important and fruitful of all portions of the equipment. This is a kind of work which, as a matter of course, can be profitably undertaken only after the student has acquired a good knowledge of the higher mathematics, including a strong course in applied mechanics, and after he has obtained a fair knowledge of the subjects which are to be made the objects of investigation. In the great engineering schools, the undergraduates are given a course of laboratory instruction in this experimental engineering work; while the labors of investigation, and of scientific or professional research, are only undertaken, as a rule, by men of maturity, graduates of the schools well-prepared by education and professional experience as well as by that natural aptitude which is no less essential, for carrying on this highest and most exacting of all scientific work. In the writer's own experience, he has, however, often seen admirable and permanently valuable work performed, with exceedingly fruitful results, by young men who had this talent and who had made themselves familiar with the art and with the state of its science, in departments of knowledge and of engineering work in which research involved no very serious intricacy of mathematical investigation or extensive scientific knowledge; while some of the very best investigations of a higher sort that he has ever known have been the work of young men making a specialty of the subject investigated.

The effect of such a training in this kind of application of the principles already learned in the class-room upon a bright student is, however, remarkable, whatever the nature of the course in which he engages. It awakens an interest in science, and in its useful applications, such as no other method of instruction can produce. It gives him new powers, new interests, new and substantial knowledge, knowledge acquired at the finger-ends as well as by the exercise of the mental faculties, and thus more real and more permanent than any "learning of the schools" purely can ever be.

The process of preparation of the equipment in this department should be similar to that already described in connection with the subject of tool-equipment. That is to say, the beginning should be made with the simpler and less costly apparatus required to illustrate the elementary or introductory portion of the course; and this selection of material should be made in such manner as to fit to each section of the course of instruction just that apparatus which will best, and in the simplest and least expensive way, exhibit its principles or its methods. Thus the instruction may be made progressively more and more complete and valuable, without in any manner neglecting the duty of thoroughness of instruction. The quantity of apparatus required will be determined by the length and the character of the work undertaken. In many schools, only a very elementary course can be given, and the apparatus will be small in quantity and inexpensive. In the more advanced schools, large sums can be profitably expended in the procurement of apparatus which will suitably illustrate a course of instruction involving the application of the most advanced courses of instruction in all the physical sciences. These courses in experimental work commonly begin with instruction in the use of instruments capable of employment in the illustration of facts and principles relating to strength of materials and other lines of work demanding the practical employment of principles and methods taught to the sophomore or junior classes of the school or college, and they are gradually extended as it is found practicable, until they include a fairly complete provision for the illustration of every scientific application of the class-room work, and in all departments of engineering, even including those of thermodynamics and the fundamental work in steam-engineering.

When the undergraduates have been thus taken care of to the limit of the collateral courses of undergraduate instruction, provision may be undertaken for graduate and original work in research. The apparatus here called for is, often, of an entirely different description from that previously demanded for the undergraduate department in experimental engineering. While the use of the same apparatus is, to a very large extent, practicable—and wherever practicable, desirable—it will be found that the special apparatus of research is often, if not usually, necessarily constructed especially for the purposes of the investigation contemplated. It is special, and therefore, as a rule comparatively costly. It is generally used only for its one primary purpose, and therefore may have only historical value when finally, the work being completed, it is set aside. Colleges must evidently, for these reasons, go into such work with the greatest caution, and it will often be found impracticable to undertake important and desirable lines of research in consequence of their costly requirements in apparatus and for labor. In such cases special contributions must be depended upon from those among wealthy and patriotic and interested men outside the college who are, in many cases, glad to do what money can toward the prosecution of such investigations. Care should be at all times taken to see that whatever apparatus is procured for special research is so made, if practicable, as to serve the general purposes of the laboratory after its special work has been completed. This, the highest and most fruitful of all work in engineering schools will prove too costly to be undertaken by any colleges but the wealthy few, and only with great caution and conservatism by them; but it is the line in which the engineering schools are to-day most rapidly developing, and in which they are doing most for the profession and for the world. The application of scientific methods to the solution of the great engineering problems looming up before the profession promises to do more for the world than has any other systematic professional work ever yet undertaken. The schools are coming to be well-springs of professional and general knowledge of fact and phenomena such as the world never before saw or dreamed of. That school which can find the men to use and the apparatus to be used in the acquirement of new facts and data, and in the revelation of new processes of nature and their useful applications for the promotion of the work of the world, will do most for all.

Fortunately it is the first part of this line of work that is most essential; the cost of the first installments of the equipment need not be great, and in time every school in which the ambition and acquirements of its faculty are commensurate with its opportunities will gradually and steadily increase the outfit, until it will, in time, become prolific of large additions to human knowledge. A small equipment of home-made apparatus in the hands of one master-mind will always prove more productive of real and valuable results than the largest and most ambitious of equipments in the hands of ever so many men of ordinary or mediocre talent.

Five thousand dollars will give a good start for a laboratory of instruction in experimental engineering; hundreds of thousands in good hands may be profitably employed for the good of the profession and of the nation. Hundreds of thousands, perhaps millions of dollars, thanks to the intelligent liberality of the wealthy citizens of our country, are being spent in the direction of the elevation of our technical schools and their work, and with more than commensurate advantage to the country. *Upon the thorough education of our engineers depends very largely the future progress of the nation.*

DISCUSSION.

Professor J. B. Johnson said he thought this was the most important subject in engineering education, now in process of development. It seemed to him that the highest engineering science in our generation is going to be directed to the study of materials and scientific methods of investigation. The application of mathematics to engineering problems has surpassed the study of engineering materials. This latter is now the most important part of engineering study.

We analyze a problem mechanically, we find the nature of the stresses for instance, then we must put something there to resist those forces, and there the knowledge of the materials is required. It remains for us to discover properties of materials as yet perhaps unknown, and methods of producing materials with properties as yet unrealized, and the methods of determining the qualitative and quantitative failures and sources of partial failure. Scientific investigation in the study of materials is the work which the engineering school is now called upon to do as it has never yet been done. It is in this direction that the schools are leading the profession, and it is in this direction that practicing engineers must come to the schools and do come to the schools for advice and information; and the schools are responding promptly to the demand.

Dr. H. T. Eddy thought the remarks of the speaker had been very specially directed toward schools of mechanical and electrical engineering, but he had reached some points that all had not succeeded in arriving at. One of these points he did not attempt to settle, but merely described the difference between those shops which are carried on with a view to make them pay their own way, and those shops which are carried on more purely for educational purposes. The underlying objection perhaps was not so put to the fore as it would be in practice when we attempt to carry on shops without profit, and purely for educational purposes, which shall give the same amount of training that those shops do which are carried on for profit. The former become very costly, and it seems possible that there may be a sort of medium course between these two horns of the dilemma, that it may be possible to keep the educational object exclusively in view and still do an amount of manufacturing for the market which will very materially relieve the financial situation which results when so large an amount of shop practice is taken as is supposed to be taken in such a course as this. This middle course consists in doing work for the institution itself, and for the building up and enlarging of the school. This is, as Dr. Thurston was fully aware, a field which some shops and laboratories have cultivated, by supplying not only machinery for their own schools, but for other schools, and it is one which can be very usefully and conveniently cultivated; but the commercial question ought never to be brought into a school in such a way as to say that the shop must pay for itself in whatever direction the education may be led by that consideration. He for one deprecated the establishment and carrying on of shops of the kind spoken of where a commercial product is the controlling factor; and the student, when he becomes adept in a particular process, is kept upon that process because it pays. It interferes with his education and he loses time and strength which ought to be used in a different direction. This is a consideration which ought distinctly to turn educators to a shop practice which shall be distinctively for educational purposes. That secondary point may be kept in mind, which will relieve the financial strain somewhat, but he distinctly desired to discountenance manufacturing for profit as a primary consideration.

Professor D. S. Jacobus agreed with Professor Eddy that the shops should not be made to give an income to the institution. The main objection found at the Stevens Institute is that if every student in the institution had the same amount of ability and was a fair machinist, then a system could be adopted whereby the work could pay and every student could be put on different classes of work. But suppose they undertake to build an engine for the trade, there are certain classes of work that you could not trust at all to some of the students, they would make a botch of it, and the work would always necessarily be given to those who had shown themselves capable of performing it, and yet when it comes to following up those very same students who cannot work very well in a shop we find in many instances they come out just as well when they get into practical things as those who are adepts in the shop. Therefore they adopt the rule that every one shall know the principle upon which work is done, and every student has the same class of work and every one has the same opportunity for learning, which could never be obtained if they had a system whereby they had to distribute the work to those students who could do it best, or even acceptably.

Professor H. W. Spangler said it had always seemed to him that the professors and the mechanical engineers stood on two entirely different planes.

There are two classes of colleges in this country, in one of which the financial question is a much more serious one than it is in the other. That is, while it is serious enough in all, the land-grant colleges are in a very different position from those which are maintained by either private subscription or private subscription in connection with tuition. It had always seemed to him that the attempt to make money out of a student, any way you put it, is a fraud on the student. The student pays a certain amount for his tuition; if his tuition is reduced in consideration of a certain quantity of work he does, it seems to be fair, but it seems to be unfair to sell the products of his labor when the student pays a certain fixed amount of money toward getting an education. That is the first business of the institution. The question of making money, making machines, making apparatus that are to be sold, it seemed to him was not only secondary, but should be put about one-hundredth in the list of things. In many institutions the tuition is low, and it is low because to a very great extent it is possible to reduce the tuition because of the vested funds of the state or what not. In other cases the tuition is high, and where this is the case he was satisfied that many young men feel that it is an imposition if, after they are able to carry out certain mechanical processes, they are obliged to continue them for the purpose of producing products which will be valuable for the uses of the school or for the purpose of sale. It always seemed to him a great misfortune that a man should spend many many days or hours doing a particular kind of work. He remembered very distinctly having to polish up a connecting rod. He considered it then and he considered it still an absolute waste of time, and he was satisfied that many others would be of the same opinion, many of his own students, if he should carry out the same system.

Professor R. C. Carpenter was of the opinion, from visiting many of the school workshops which are being conducted, the system which is now in practice throughout the country is a sort of a mixed system, started with exercises, and making those exercises, so far as practical, of use to the school, and it seemed to him to be working very well. It did not seem to him that it would be practically as these gentlemen have described it, that is, he did not think the students have felt bitter at leaving in the school some specimen of their handiwork which will be useful to the school in the future. In fact he thought that they have taken pride in the matter of producing something which will be used. It had always struck him that in the management of these shops there must be a sort of spirit of enthusiasm produced in the students in order to get very good results, and that enthusiasm cannot be produced over dry exercises that go into the scrap heap after they are done. They went to see something which will live. Of course that cannot be produced until the student has a certain amount of skill, but he thought so far as possible the exercises should be made of a practical form, and should always follow the course of having the student first instructed in the use of tools by these exercises that have been described.

Professor Ripper thought he should be stating what would be the opinion of some of his colleagues from England if he should say that this question, now under discussion, does not come to the front there at all. In all their colleges in England their shop work is conducted in the interest of the student only. They do not, on any account, undertake work for commercial purposes. He believed there is one institution in England that does that, but it is a very severe exception. None of them would entertain for one moment any proposal to do work for sale. In regard to the work in the shops, he found it a very good thing indeed to allow the students to make things which, while they give them an excellent training, shall afterwards, when made, be the property of the student himself. He had found that exceedingly effective in getting up enthusiasm and in getting some really first rate work done. For example, his students have to make themselves a complete set of work-shop tools, squares, centre punch, spirit level and quite a large stock of interesting and useful tools. These are their own property when made, and the work was not allowed to pass until it was thought to be as perfect as it was reasonable to expect. The consequence was that, though they give quite a limited time to the work of shop instruction—practically one day in the week—yet at the end of the session they get some very good work done. They have also a number of workmen in the shop carrying on and doing work for the institution, and the advanced students help them. The question of the sale of work does not enter into this question there at all.

Professor S. W. Robinson thought the students might be classified with profit. The laboratory or shop work, as it has been called, divided into several classes, the first class involving merely the production of form on the part of the student without reference to dimensions. If the student is required to do two things he is very likely to fail in one or the other. He found it unwise to ask a student to file a piece square and to a certain size at the same time. There should be a division into form and dimensions and after he has the form, then he may use his rule and calipers to work to size. This is merely an example of the work that should be done all through the course in shop work. In turning on the lathe, for instance, if the student wishes to turn a simple cylinder, it is hardly possible for him at first to produce a good cylinder to a certain size. He had been in the habit in that case of having the students undertake to turn the pieces first, trying to produce the correct form and surface, and let the dimensions come afterwards.

He thought that this matter of the production of work for useful purposes should, if done at all, be put in its right place. He would not attempt to produce work for a useful purpose as the first thing the student does, or very near the first of his shop work probably. A student should have at least one year's practice before attempting to make anything for commercial purposes, and even then he will find that his work is poor enough. He had had experience in both systems, in places where they thought the school shops should pay, and also in places where the students worked on pieces that went into the scrap heap. He thought the latter was the better. If the two must be, he would favor putting off the commercial part of it until the student had had considerable experience in producing what should be produced. If the student has enthusiasm for making something, as had been said, let the time for that be taken in vacation, or time outside of the time used by the student in shop practice.

Professor H. H. Tracy said that while he did not wish to judge of the merits of the two systems in use, especially after such eminent men had discussed them in full, he could not refrain from saying a few words in defense of the first named system, *i. e.*, that of the Worcester Polytechnic Institute. Being a graduate of that institution, he could but feel that the impressions which some of the previous remarks would convey were erroneous. Professor Robinson's difficulty in getting the student to work to size and at the same time learning *how* to work is a natural one. While he is directing his attention toward quality, he forgets quantity, but it seemed to him this is largely overcome by the method of training in wood-work spoken of by Dr. Thurston. If he was not mistaken, that preliminary course of wood work precedes the ironwork in practically all of the manual training schools.

It was his experience that this training in making a set of patterns which must stand a severe test of measurement is such in the Worcester school that when the student gets to the machine shop the number of spoiled pieces from poor workmanship is exceedingly small. Professor Jacobus's point would be a good one if strictly applicable. There is but little work, however, in the great variety found at the Worcester shops which any student is not required to do. In fact, in order that a man may not repeat any one class of work from week to week, a record is kept of each piece or class completed, and because he is exceptionally skilled on any particular piece, he is *not* kept upon that as stated. Were he speaking of an apprentice in a downtown shop he would have been perfectly correct.

In regard to the selling of the products being an imposition upon the student after he has paid his tuition, it seems to him to be a matter of opinion. He had never yet seen the student who was not proud that he could make an article that was fit to be sold instead of being dumped into the waste heap. He will do better work, take more interest, and consequently make more rapid progress when he feels that his product is to have a value in itself. Professor Carpenter speaks the mind of the student exactly when he says he likes to feel that he is making something useful and that his work is to be accepted in place of that of a more skilled mechanic.

There were a great many things that could be said in favor of this system if time permitted, but he would suggest to those who have had experience with the "model system" alone to visit the Worcester shops and see for themselves the advantages of a practical training.

THE HYDRAULIC LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

By DWIGHT PORTER,
Associate Professor of Hydraulic Engineering.

This laboratory has been arranged and equipped upon an extensive scale for experimental researches and practical tests in hydraulics. The apparatus is used by the students of nearly all the engineering courses in regular laboratory exercises, during which they work in sections no larger than strictly necessary for conducting the particular experiment in hand. Such work is designed to give the students a practical demonstration of laws with which they have become familiar in a theoretical way only, to acquaint them with the appearance and behavior of certain standard forms of apparatus and to teach them the methods and precautions commonly necessary in hydraulic experiments. The time allotted to any one variety of work is what seems sufficient fairly to attain the above ends, and no more, it not being proposed in class exercises to make the young men adepts, nor in general, to achieve results of especial scientific importance. In connection with thesis work, or the studies of post-graduate students, special apparatus is every year devised and installed, suited to original investigations and to the securing of results of permanent interest and value.

The space devoted to the hydraulic laboratory covers about thirty by fifty feet on each of the two lower floors of the engineering building. The primary source of water supply is the city main, but it is rarely that draught is made directly upon this during an experiment, water being directly supplied from pumps, which in turn, draw from a large receiving pit sunk below the basement floor, the discharge from all experiments finding its way to the pit and thus being used over and over. Several pumps are in use, steam, rotary, and centrifugal, supplying the different apparatus. In order to secure a more constant pressure than that from the pumps, for certain kinds of experiments a ten-inch stand-pipe, eighty feet high, has been built, reaching to the top of the building. The supply to this from the pumps may be so regulated by valves and overflows, conveniently arranged on each floor, that the head shall be kept at any desired point during an experiment, with a fluctuation of scarcely one one-hundredth of a foot. Many of the pieces of apparatus have been so arranged that they can be run at will under pressure either from the stand-pipe or directly from the pumps.

An important feature of the plant is a closed steel tank, five feet in diameter and twenty-seven feet high, extending from the basement floor upward through two stories. It is connected at top and at bottom with the stand-pipe previously mentioned, and at four points on each floor is arranged for the insertion of orifices, free or submerged, mouth-pieces and other fittings, and for connections with motors and experimental pipes.

It is fitted with hydraulic gates so planned that an orifice, for example, may be quickly exchanged for another without the necessity of drawing down the water in the tank.

For certain experiments on the flow of water through pipes, three lines of three-inch pipe have been erected. One of these is of iron, with a Venturi meter inserted in its course; the other two are of brass, very carefully made, with piezometer connections of approved form at sundry points. One of the brass pipes is arranged for the insertion of diaphragms with orifices of various sizes; and the other for the insertion of short experimental pieces of pipe provided with side orifices, branches or other devices. The discharge from the various pipe lines passes finally through a hose nozzle, with pressure-gauge connection to be used in determining the cœfficient of discharge. The nozzle discharges into a movable double chute, through one branch of which the flow may be wasted until it is desired to begin an experiment, when the other branch may instantly be thrown into the path of the jet, and the water directed through the floor into a measuring tank beneath.

For delicate observations upon the velocity at any given point in flowing water, the laboratory contains three different instruments embodying the principle of the Pitot tube. Two of these, for use respectively in jets from nozzles and in streams flowing under pressure through pipes, are the property of Mr. John R. Freeman, by whom they have kindly been placed at the command of the institute. The third, for jets from standard orifices, has been designed especially to use on the large tank which has been described. In each case, the pressure of the flowing water due to its velocity is transmitted through a minute orifice and a connecting tube to a mercury gauge, the reading of which indicates the velocity at the tip of the tube. A simple attachment to the last mentioned of these devices has permitted measuring the shape of the jet and the size of the contracted vein with the greatest nicety.

For measuring the quantity of water discharged during experiments, the common method employed is that of weighing, the temperature of the water being at the same time observed. Thus, in determining the co-efficient of discharge of standard orifices, the flow from the orifice passes into a large cask, with ample discharge pipe and quick-acting valve at the bottom, and thence into another and similar cask underneath, resting directly upon scales. The upper cask serves for temporary storage while the contents of the lower one are being weighed and discharged. By this means, with casks of moderate size, it is not difficult to weigh continuously at the rate of forty thousand or fifty thousand pounds of water per hour. Again, the discharge from experiments on the second floor may be diverted through chutes to any one of several measuring devices on the floor below. One of the most important of these is a cylindrical steel tank, six feet in diameter and ten feet high, capable of holding some two hundred and eighty cubic feet of water. This tank is conveniently placed for drawing off and weighing the contents, and is by this means calibrated. In order to determine the quantity discharged into the tank in any experiment, it is then necessary only to read a glass gauge attached to the tank and provided with sliding sight and vernier. For more indirect determinations of quantities of water, the laboratory contains a number of weirs of different lengths, up to four feet, a calibrated orifice tank, venturi and other water-meters, nozzles and standard orifices.

The pieces of apparatus which have been mentioned will suggest to the mind a great variety of experimental work to which they are suited, and to much of which they have actually been applied. The laboratory further contains a Pelton water-moter, a small Swain turbine, a Douglas hydraulic ram and a variety of dynamometers, mercury gauges, piezometer fittings, etc. There have also been placed in the laboratory a large number of finely constructed orifices and metal pieces of sundry descriptions, which were used many years ago by Uriah Boyden and James B. Francis in their famous experimental work at Lowell.

The plant which it has been sought to describe has been designed with a view to extensive further developments, important advances in which are likely to be made every year. It has been steadily taxed to its utmost capacity, both for regular class exercises and for thesis work, and fully commends itself as a substantial aid in engineering education.

DISCUSSION.

PROFESSOR MERRITT asked how many hours are spent by each student in the laboratory. Does he perform a wide range of experiments, or only a few carefully selected ones?

Professor Porter replied that the laboratory work is taken in connection with other work, and the exact time in the laboratory cannot be stated, but is probably about thirty hours. Each student performs a few selected experiments.

Professor Goodman called attention to a proposition made by Professor Lanza that the work at the engineering laboratories throughout the world should be arranged similar to that of the different astronomical observatories. Each observatory takes up and studies a certain part of the heavens, and in that way they all cover a very large field with great thoroughness. He recommends that one college take up some special class of work and do it as thoroughly as possible and communicate the results to the rest of the associated engineering laboratories. Of course, every one associated would have the benefit, not only of their own observations and results, but of others. "Some very valuable work might be done, and the trouble often lies in not knowing what has been done. It is really annoying for an observer to undertake original research work, and then find out that somebody else has done it better than himself, and that the whole of his work might have been saved, or spent in some other direction to greater profit." He thought the subject worthy of consideration and hoped some such arrangement could be made.

Professor Robinson called attention to the Pitot tube as a means of measuring the flow of water, air, oil, and natural gas. "The only precaution to be observed in its use is to see that the joints are thoroughly tight, and that the Pitot mouth be a fairly long one, and that the side outlet be not a single one." As far as the speaker knew, the first use of the Pitol tube for measuring the velocity of air was in 1873. He had since used it extensively in measuring the velocity of the flow of natural gas in pipes.

Professor Talbot asked the author of the paper if they made any experiments in more advanced work.

Professor Porter explained that they did, and cited, as examples, the determination of the velocity at different points in the cross section of smooth and rough pipes, and the measuring the size of the jet issuing from a free orifice.

THE TEACHING OF GRAPHICAL METHODS IN ENGINEERING COLLEGES AND SCHOOLS.

By H. S. HELE-SHAW,

M. Inst. C. E. Harrison Professor of Engineering, University College,
Liverpool, Eng.

When the author was invited to prepare a paper to be read before this important congress of those interested in engineering education, the subject of "The Teaching of Graphical Methods in Engineering Colleges and Schools" seemed to him to be a very desirable one for consideration.

It is necessary to commence by pointing out that the subject has apparently never yet been treated from an educational point of view, so as to comprehend its whole range in a general manner.

Graphic methods may be classified in two divisions. *First*, the plotting of results; *second*, the solution of problems.

The former of these is rarely considered worthy of any special training, as a knowledge of it is apparently regarded as capable of being acquired without any instruction.

The solution of problems, on the other hand, has of recent years received a good deal of attention, under the title of "Graphic Statics," which is the most important, although at present only a special branch of the application of graphical operations. This branch is in many engineering schools dignified by a special course of lectures and classes, and even a special professor in the subject, while in many other schools the subject is not taught at all; and again, the opinions held by practical men, and apparently also by professors in the engineering sciences, would seem to differ in a most remarkable manner as to the value of graphical methods. The author believes that this difference of opinion is apparent and not real, and the very fact that so much attention has been devoted to the subject, in which at present there is no uniformity in the teaching nor general agreement as to methods, amply justifies the treatment of this subject before a congress such as the present, and it is with the hope that some authoritative expression of opinion may be obtained that he ventures to bring it forward, notwithstanding that there may be many present better able to deal with the matter than himself.

It will be better to deal with the two divisions in order, taking first the

PLOTTING OF RESULTS.

This method is now universal, not only in the mechanical sciences, but in almost any case where statistics of any kind are employed, as it enables results which would otherwise be difficult to grasp to be at once made clear by a simple inspection. The various methods of plotting, and the various instruments which have come into use for automatically recording such results are too familiar to need discussion. A full treatment of this subject was presented by the author last year to the British Association in a "Second Report on the Development of Graphic Methods in Mechanical Science," in which it was pointed out that not only in ordinary engineering, but in naval architecture and the study of electricity, much has been contributed to the progress of science by this method. The classification of references to scientific periodicals and transactions, which occupies one hundred pages of that report, shows that the custom of plotting such results has greatly increased. When once the plotted diagram is drawn, or obtained, interpolating the result is one of the simplest kinds of operation, but nevertheless it represents a mathematical process which would be extremely difficult and often impossible. This method of interpolation is becoming more and more adopted, and books of rules, such as "Molesworth's Pocket Book," give plotted results on various spans of girders or for moving loads. Foley's "Mechanical Engineer's Reference Book" gives curves for the expansion of steam, the proportion of valves, the extension and loading of springs, the co-efficient of friction, the proportion of the teeth of wheels, the proportion of belts, the strength of ropes, the displacements of ships, the proportions of propellers, bolts, pipes, boilers, furnaces, girders, coal consumption, etc., from which it intended to actually obtain graphically any required result by interpolation.

Again there has been no more striking development of automatic processes than in instruments connected with the automatic plotting of results. This also the author has treated at some length in the British Association report already referred to, and he need therefore only call attention to the large and varied number of instruments which include anemometers, barometers, chronographs, hygrometers, dnynamometers, speed recorders, hydrometers, meters of all kinds, pressure guages, pyrometers, tide guages, thermometers, ammeters, voltmeters, galvanometers, chronometers, etc. There are also numerous instruments of a compound nature, recording several operations at once, which scarcely come under any classification, such as instruments for exhibiting at one view time, pressure, speed, and temperature connected with an engine; instruments for giving a weekly diagram for speed; and pressure instruments for recording the number of checks and the time given in by workmen.

Now it appears to be the common idea that the interpolation of results, no less than the actual plotting, is a sort of intuitive process which is readily acquired, and requires no sort of training, but the author has found on careful investigation, that the contrary is the case. This may be illustrated by an example. The series of diagrams relating to the action of the crank and connecting rod of an ordinary engine, which are now exhibited, and which were drawn for a meeting of an engineering society, will be noticed to be in some respects novel, being arranged so as to include four sets of diagrams, giving different data, each set of which includes a linear, a central polar, and a circumferential polar diagram of the same results. To many of those present these diagrams may be perfectly familiar, but the author found many practical engineers to whom not only did the different series of diagrams have no definite meaning, but the difference between the three diagrams in each and the points which are brought out by their means were obviously not easily grasped. Moreover, from year to year when bringing similar diagrams before students, they have found the greatest difficulty in at first understanding them, and only after considerable repetition and after the student has constructed for himself a series of such diagrams, has he seemed able to deal with or to grasp their general meaning.

THE SOLUTION OF PROBLEMS.

With regard to the solution of problems, the case is entirely different, for this subject receives a certain amount of attention in every engineer's course. In England such instruction is given as a rule in most colleges incidentally, when the subjects of statics, machines, or hydraulics are being dealt with, although recently in some cases special training in graphical methods is being introduced as a part of the course of engineering instruction, in several cases being given as a branch of descriptive geometry. Thus, in the science and art department, both under the heads of descriptive geometry and also of machine drawing, a knowledge is expected of some of the elements of the subject. On the continent of Europe, however, for many years not only have special courses of lectures been devoted to the teaching of graphical statics as a separate branch of the subject, but there have been a large number of schools in which there are special professors of graphical statics. The reason for this difference is to to be found, not altogether as it is often supposed, in a want of appreciation of the subject on the part of English engineers or professors, for it was in England that the germ of such methods was first developed by Rankine, Clerk Maxwell, Fleming Jenkin and others; but because the system of appointing professors in the special polytechnics devoted to the allied sciences is in vogue, rather than in England, where one or two chairs of engineering are added to other chairs of literature, arts and science of the university, or university college.

The author has been at some pains to collect the details of instruction at continental schools, and the summary of results of the hours of teaching, and the schools in which it is taught, is presented at the end of this paper, though at present the list must be regarded as incomplete, from the difficulty which has been experienced in acquiring information. There are also added translations of the detailed syllabi of instruction which have been selected from the engineering schools of Liege, of Milan, of St. Petersburgh, and of Hanover and Braunschweig, in Germany. The author, although he has written for information, has not yet been successful in obtaining a return from the different universities in America, but he hopes to add these also as an appendix, for there are not wanting instances of eminent professors who have devoted much time to the development of this subject, notably Professor Eddy, of the Rose Polytechnic Institute.

Now, it is important to note the general method of instruction which these syllabi indicate, and which are even more clearly shown in the various text books on the subject. From these it is clear that the general methods consist of giving certain rules, which may be called general graphic methods, and which apply to addition, multiplication, powers and extraction of roots, and which may be regarded as forming the introductory portion. This is followed by an introduction to statics in which special stress is laid on geometrical constructions and the solution of many problems are given which would otherwise be worked out by analysis.

We may regard the well known work of Culmann "*Die Graphische Statik*" as the first important treatise of the kind. In this work were collected problems of a general nature, under the title of "Graphical Calculation," which occupied the first three chapters, under the respective titles of "Operations with Lines," "Rectification of Areas," and the "Rectification of Solid Bodies," the whole comprised in seventy pages. In the second edition of his work two chapters are introduced on logarithms and calculating rules, this portion occupying, in the second edition, 150 pages. In the second edition, the preliminary portion of graphic statics, which occupied 130 pages in the first, here takes up no less than 350 pages, and is followed by 120 pages on the theory of the elements of elasticity, its author unfortunately not living to complete the work on the lines which he had planned out. One thing is particularly noteworthy, viz: the large space occupied by constructions and propositions which may be regarded more or less of a general nature, compared with the space devoted to the solution of actual examples. The same thing occurs in the lucid and valuable work of Bauschinger, "*Elemente der Graphischen Statik*," in which there are sixty-two pages devoted to what may be regarded as matter of a general nature, and only thirty to the applications. In the work of M. Levy, which is the standard work of France, although he has very much reduced in the second edition the portion of purely geometrical caluculation, the whole of the first volume, of between 500 and 600 pages, is devoted to the "Principles and Applications of Pure, Graphical Statics." The same facts are derived from a study of the detailed course as set forth in the various programs of technical schools.

The conclusion is that a great deal of the matter taught under the head of "Graphical Statics" contains general principles of graphic methods of construction which might be taught apart from any applications at all, and being so taught it would be capable of application, not only in cases of statics, but in dynamics and hydromechanics. Take as an example of the proposition of the ellipse of inertia and the central ellipse, which are only applied to force, and which are given as if they referred only to the problem of the beam, but which have an equally important bearing in hydrostactics and rigid dynamics, the ellipsoid of inertia having the properties for instance of the momental ellipsoid of Cauchy, the central ellipsoid those of the equimomental ellipsoid of Legendre. Indeed, there is every indication of a gradual tendency towards the development of the science of graphical calculation quite apart from that of graphic statics. Thus we find graphical constructions originally devised and given by writers (notably Rankine) as they were needed in works of mechanics.

Next we have the first collection of graphical calculation, already referred to, of which there is remarkable examples in the little work of Cremona. "Il Calcolo Grafico"* in the preface of the English edition of which he acknowledges the work of Culmann, but goes considerably beyond that author, particularly in adding the important chapter on "Centroids" in which the properties of the centre of gravity are treated from a purely geometrical point of view without any reference whatever to force. A still more recent work is that of Favaro, who in his "Lessons on Graphical Statics" devoted his second volume entirely to the subject of graphical calculations.

From this it is clear that a course of instruction might be given under the head of graphical methods, which might be taught in the same way as descriptive geometry, and which ought indeed to be worked in conjunction with that subject. Graphical methods should comprise the constructions of such geometrical figures as are important for graphical application, should deal with the plotting of results and the general properties of plane curves, as far as the student is able to numerically effect measurements with it, which he can check by calculation and which he should be expected to work out with accuracy and to regard the results he obtains as being sufficiently accurate for practical work, although such examples need not in the first instance be applied by him to any practical engineering problems. Thus for instance, the proposition of projective geometry so far as the null or focal system is concerned, and the projective properties of bodies, and of the pole and antipolar, might be taught, although the whole subject of projective geometry is not necessary for engineers; and, unless it is desired to study the higher branches of the subject, there is no necessity whatever of a treatment such as Culmann has given in his chapters on the "Projective Relations between the Polygon of Forces and the Funicular Polygon" and "The relation of a System of Forces with the Null system, and with Curves of the third Degree, or of the Co-linear and Reciprocal Relations of the Funicular and Force Polygon."

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* Now translated into English by Professor Hudson Beare, and published by the Clarendon Press, Oxford.

AN ELEMENTARY GENERAL COURSE.

There appears to be no reason, therefore, why an elementary course of a general nature, specially arranged so as to include all that an ordinary engineering student requires to know of graphical methods, should not be introduced as a regular subject in engineering schools, and the following arguments may be brought forward in support of this view.

1. Although the time tables of an engineering department are already full, yet it will be found that a course such as that suggested really includes much of what is taught at present in a desultory way, and such a course would obviate some of the teaching given under the heading of "descriptive geometry," so that during one or two terms of a year, it might be taken during the same hours as are already devoted to descriptive geometry, with possibly one lecture a week for one term, in the place of the actual lectures in applied engineering, into which at present graphic methods are often obliged to be introduced for the want of proper preliminary training in the subject by a student. Moreover, the time now devoted in the engineering laboratory to the plotting of curves might much better be occupied in the drawing-room itself, in connection with the practice of the plotting and interpolation of curves as a part of the subject of graphic methods, the data obtained from the engineering laboratory affording useful information.

2. The time spent in such graphical work would be an excellent discipline in accurate drawing for a student who is often inclined to regard a sketch, roughly representing an idea, as sufficient for practical purposes. A student should learn for himself that nothing is so easily deceived as the eye. The following illustration may be cited in support of this, by which it may be proved conclusively that things which are equal to the same things are not equal to one another. That is to say, if A, B, C, D, Figures 1 and 1a, is a rectangle, and the line DE is drawn equal to

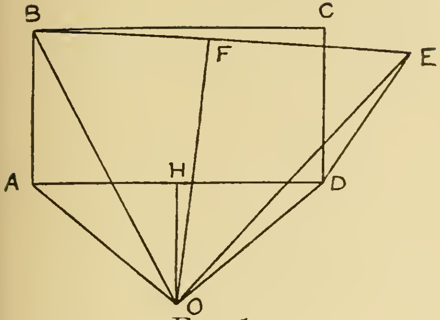

FIG. 1.

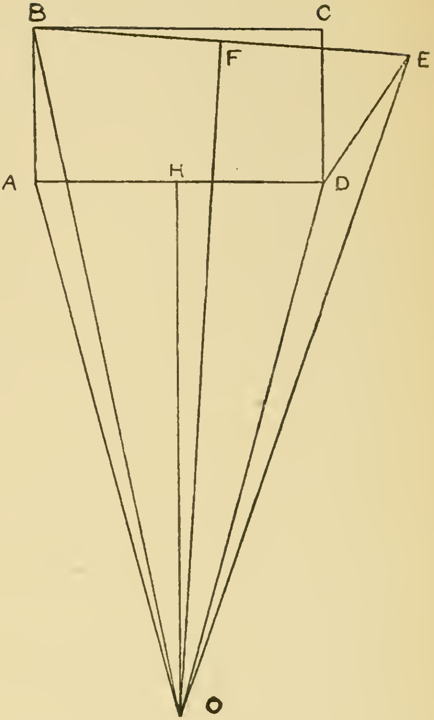

FIG. 1a.

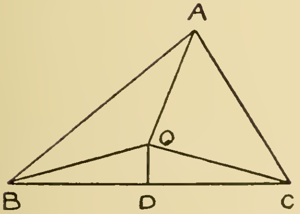

FIG. 2.

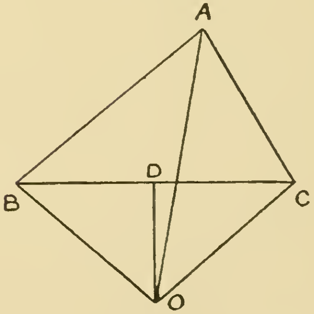

FIG. 2a.

DC, and E is joined to B, and BE is bisected at F, and AD at H by perpendiculars through H and F, their perpendiculars are prolonged so as to intersect in O, and OA, OD, OB, OE are joined, it can be proved that

$$\left.\begin{matrix}\text{ODC}\\ \text{ODE}\end{matrix}\right\} = \text{OAB}.^*$$

In the same way, Figures 2 and 2a may be drawn as an illustration. If in the triangle A B C, D O bisects B C at right angles, and O A bisects B A C, O A being sketched so as to bisect the angle B A C, then it may be proved that

$$\text{A B C} = \text{A O C},$$
$$\text{A C B} = \text{A O B}.$$

It is quite true, as Professor Culmann says in the preface of his work: "The constructing engineer will give preference to geometrical solutions wherever an accuracy of results up to three significant figures 1-1000th), which can be perfectly well obtained, is sufcient, for his drawing instruments are always at hand."

Drawing is his habitual expression of thought, "his language," and thanks to his topographical and

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* To persons unfamiliar with this fallacy, it should be explained that the error is in the drawing of the figure. Thus, in this problem, when properly drawn, the point O is always as shown in Figure 1a, so that OE always falls outside of D. Then we have

$$\text{OE} = \text{OB},$$
$$\text{OD} = \text{OA},$$

since both are drawn from a common point on bisecting perpendiculars to the extremities of the base line. Also

$$\text{DE} = \text{AB}$$

by construction, hence in the triangles OAB and ODE we have the three sides of the one equal to the three sides of the other, and hence,

$$\text{ADE} = \text{OAB} = \text{ODC}.$$

Similarly, in Figure 2, which will always fall as in 2a, the four points, A B O C, fall in the circumference of a circle, since the equal angles at A are subtended by the equal lines, OB and OC, which must then be chords in the circumference through the four points. It then follows that

$$\text{ABC} = \text{AOC},$$
$$\text{ACB} = \text{AOB}.$$

—Ed.

geodetical training, he is more accustomed to judge as to the exactness of sections, and to define lines and points with great precision than the architect or mechanician, but such accuracy in drawing is by no means naturally or intuitively acquired, and students require training in a course of graphical methods before he would appreciate their value. Moreover, such practice in actually performing the operations and becoming familiar with the solution is absolutely necessary, if it is to be expected that a student will really use these problems afterwards in his practical work, as such modifications become extremely puzzling owing to the want of a thorough acquaintance with the methods.

3. It is not only necessary that a student should be familiar with accurate drawing, but also that he should be familiar with graphical constructions as a means of solving problems. The plan ordinarily adopted in the teaching of statics, in conjunction with graphical methods themselves, seems expecting too much for the capacity of an ordinary student, and the author has attributed the difficulty of getting a class of even intelligent students to correctly solve problems out of the beaten track, to the difficulty involved in combining these two things. In the use of ordinary geometry or analytical methods there are separate classes for algebra, analytical geometry, trigonometry, and yet the ideas involved in them are no more difficult than those included in graphical constructions and methods, and graphic methods have the same claim to be considered as a separate branch of study.

The author, therefore, wishes to bring forward the following proposition: That in all engineering schools there may with advantage be introduced a separate course in graphical methods, which shall deal with such problems as have a practical bearing in mechanical science, and which do not involve applications to any concrete subjects, such as statics and dynamics, *but which may familiarize the student by means of examples accurately worked out by himself with methods which he will be able afterwards to apply.*

APPENDIX I.

Courses of Instruction in Graphical Methods in European Engineering Schools and Colleges.

ROYAL TECHNICAL HIGH SCHOOL, BRAUNSCHWEIG.

Time--Two hours weekly for one half year.

Graphic calculation—Chief aspects of graphic statics—Force and rope polygon—Relative properties of structures—Combination and resolution of forces—Center of gravity—Moment of forces—Moment of inertia—Stress diagrams—Application of graphic statics to various examples. (Technical mechanics and descriptive geometry must be studied previous to the last course.)

ROYAL TECHNICAL HIGH SCHOOL, HANOVER.

Time—Two hours weekly, and two hours weekly for exercise class, for one half year.

Transformation of areas—Force and rope polygon—The applications for finding the center of gravity and moment of inertia and also to beams, framework, retaining walls, and arches. (Elasticity must be studied previously or concurrently.)

SCHOOL OF ARTS, MANUFACTURES, AND MINES, LIEGE.

1. GRAPHICAL CALCULATION—Rule of signs and notation—The four first operations—Powers and roots—Calculating instruments—Areas with straight line perimeters—Transformation of curved figures and solids.

2. GRAPHIC STATICS—(1) Geometrical properties of the funicular polygon, and of reciprocal figures—(2) Composition of concurrent forces

and of forces in a plane—(3) Moments of forces situated in the same plane—(4) Infinitely small forces the lines of action of which are situated at an infinite distance—(5) Study of the equilibrium of bodies, solicited by forces situated in the same plane—Case where the body is held at one or two fixed points, or against one or two fixed surfaces—(6) Equilibrium of polygon—1st closed, 2d open-jointed and having its extremities fixed. Equilibrium and stability of an arch—(7) Study of the polygon of forces, and of the funicular polygon in their relations with conics—(8) Mechanical theory of reciprocal figures, and determination of efforts of tension and compression in a jointed system of bars—(9) Composition of forces in space—System of parallel forces and center of gravity—(10) Action of external forces on a solid—Determination of shearing effort and bending moment produced by fixed and movable loads.—Dangerous section.—(11) Maximum moments exerted by a movable load upon a beam, abutting its extremities—(12) Moments of the second order—Their graphic representation for a system of parallel forces of which the points of application are in the same plane—Moment of inertia and radius of gyration in relation to any axis—Conic of inertia—Ellipse of inertia and central ellipse—Systems of parallel forces of which the intensities are proportional to the products of elements of a plane area by their distance from an axis—Noyan (Kern) of a plane area—Construction of the central ellipse and of the noyan of inertia of plane figures—(13) Method of funicular pencil—Application of composition forces to the calculation of a system of bars—(14) Graphic integration—Definitions—Methods of the funicular polygon and funicular pencil—Applications.

ST. PETERSBURG.

Time—One hour weekly during one year, with exercises arranged.

I. GRAPHICAL STATICS—Graphical methods for finding a resultant of several forces acting in a plane—Scharnieur's Polygon—Geometrical relations between different Scharnieur's polygons for the same system of forces—Applications—Parallel forces—Finding of resultant and the sum of moments—Finding of the reactions in case of a beam supported at both extremities—Polygon of moments—Its application for finding the bending moments and sum of shearing forces for any section of the beam—Cases when the forces are distributed along the beam uniformly or otherwise—Finding of the angles made by the tangents to the line of resistance (elastic line) and the construction of the line of resistance—Determination of the supporting forces and bending moments of continuous beams—

Beams with their ends encastre—Graphical determination of statical moments, centers of gravity, and moments of inertia of plane figures—Kerns of sections—Graphical methods for finding the stress in different members of trusses and girders and other systems with Scharnieur's combinations—Ritter's method—Construction of reciprocal diagrams after Clerk Maxwell—Illustrations—Duality of constructions in graphical statics and the reciprocal relations between the obtained figures—Theory of reciprocal polyhedra and its application to graphical statics.

ROYAL TECHNICAL INSTITUTE, MILAN.

I. Graphic Statics.—Time.—Two hours weekly.—(1) Products powers, roots, logarithms, division of angles,auxiliary curves, amplification of diagrams, closed circuits—Theorem of Mobin's for the parallelogram—Reduction to lines of surfaces and volumes—Transformation and division of plane figures—Lines of compensation between arcs of unit value, equal or different—Integral curve—Graphic tables and scales. (2) Composition and resolution of force in space and in a plane—Infinitely small and infinitely distant force—Linear reduction of moments—Polygon of forces and their general properties—Different properties of the funicular polygon connecting systems of parallel forces, and of kindred lines—Equilibrium of systems of chains—Tensions of springs. (3) Centre of parallel forces—Centre of gravity of points and corresponding geometrical theorems—General rules and auxiliary methods to find the centre of gravity of lines, areas, and homogeneous solids—Forces distributed along a line of resistance—Construction of differential equations of funicular curves corresponding to a given area of load. (4) Composition of forces in space—Conjugate resistance—Polar (forcal) system—Tetrahedron of forces—Reciprocal polyhedra—Reciprocal figures according to Maxwell—Cremona—Framework, simple and compound, determined statically—General rules—Auxiliary methods for graphical calculation. (5) Moments of parallel forces—Conjoint antipolar system and case of the the hypothesis of parallel forces applied to the point of resistance—Moment of inertia, centrifugal moment, polar moment, modulus of a resistance of any plane figure, antipolar system—Geometrical properties and mechanical properties of a kernel—Geometrical constructions of the kernel of any simple figure (parallelogram, triangle, trapezium) and allied determination of the respective antipolar systems, central ellipse and kernel of a circle of an ellipse, of the segment of a parabola—General rules of auxiliary methods to ascertaining by the polar system of any plane figure from given data—Different problems relating to a cylinder of any section whatever, and to forces distributed over a plane area—Centre of gravity of a surface and volume of revolution—Complement to the rules of Guldinus—Centre of pressure. (6) Bending moment and shearing force of a straight beam loaded directly and indirectly—Relative diagrams—Reaction of supports and section of greatest danger—Line of influence of Frankel—Polygon of addition of Winkler—Theorem of Levy—Bending moment and shearing force of a solid with curved neutral axis—Diagrams and corresponding theory—Diagrams of moments and shearing forces—Continuous beams. (7) Internal forces—Simple and compound bending and graphical construction of united maximum forces—Problems for the construction of a section, satisfying given conditions, and having a given modulus of resistance and moment of inertia (8) Straight beam of constant section —Determination of the section—Variation of the united maximum forces from one extremity to the other—Straight beam of equal resistance, and determination of their form (longitudinal section) under different conditions—Elastic line and its differential equation—Theorem of Mohr —Application to straight beams on simple supports, or encastre at one or both extremities—Conditions of stability and of arches.

II. Drawing Class in Graphical Statics. Time.—Five hours weekly, for one-half year. Spiral of Archimedes, equiangular spiral, logarithmic curve, catenary, etc—Graphical exercises in products, powers, roots, logarithms, resolution of numerical equations—Measurement and division of areas and volumes—Division of field lines of boundary, etc.—Graphical calculation of movements of the earth —Lines of pressure in an arch, and tension in a catenary—Exercises in composition and resolution of forces and of couples, system of chains—Construction for shearing force and bending moment for any section of a straight beam resting on two supports, and variable loading, fixed, moving, concentrated and uniformly distributed representive curves—Section of greatest danger, reactions of supports—Exercises on beams loaded indirectly—Constructions in tension and compressions of a jointed girder —Constructions relating to the movements of parallel forces, allied antipolar system, conic of inertia, principal axes, etc.—Centre of gravity, central ellipse, and kernels of sections used in practice, constructions and relative applications, centre of pressure, hydraulic wheels, etc.—Exercises on problems of simple and compound bending—Determination of the dangerous section of a beam, given all its external forces—Construction for internal forces—Elastic line—Exercises on interpolation and least squares.

APPENDIX II.

DATA ON THE TEACHING OF GRAPHICAL STATICS IN EUROPEAN ENGINEERING SCHOOLS

COLLEGE.	Term	Part of the Year	No. of Lectures per week	No. of Exercises per week	Branch of Engineering.
Aachen	2	Wint.	3	2	Civil.
Aachen	2	......	3	2	Mechanical
Berlin	3	....	2	2	Civil.
Berlin	3	....	2	2	Mechanical.
Berlin	3	....	2	2	Naval.
Braunschweig	3	......	2	2	Civil.
Braunschweig	3	......	2	2	Mechanical.
Braunschweig	3	....	2	2	Electrical.
Darmstadt	.....	.....	1	Arranged.	Private.
Dresden	5	Sum.	2	2	Civil and Surveying.
Hanover	3	....	1	0	Civil.
Hanover	4	Sum.	0	2	Civil.
Karlsruhe	3	Wint.	2	2	Civil.
Karlsruhe	3	....	2	2	Mechanical.
Karlsruhe	3	....	2	2	Electrical.
Liege	2	Sum.	3	Arranged.	Mechanical and Civil.
Munich	3	....	3	0	———
Milan	1	Wint.	2	9 (Mech. 5)	Civil, Mechanical and Electrical
Milan	1	Sum.	2		Civil, Mechanical and Electrical
Stuttgart	3	......	3	2	Civil.
Stuttgart	1	......	1	None.	Mechanical.
St. Petersburg	5 & 6	S.&W.	1	None.	Mechanical and Civil.
Zurich	3 & 5	Year.	2	None.	Civil.

APPENDIX III.

DATA OF THE TEACHING OF GEOMETRY IN EUROPEAN ENGINEERING SCHOOLS.

COLLEGE.	Terms	Part of Year	No. of Lectures per week	No. of Exercises per week	Branch of Geometry.	Department of Engineering.
Aachen	1	Wint.	4	4	Descriptive.	Mech. & Civ. El.
Aachen	2	Sum.	5	4	Practical.	Civil.
Berlin	1 & 2	Year.	4	....	Analytical.	Civil & Mech.
Berlin	1 & 2	Year.	5	5	Projective.	Civil.
Berlin	1 & 2	Year.	4	4	Descriptive.	Mechanical.
Braunschweig	1 & 2	Year	3	.. ..	Analytical.	Civil Mech. Elec.
Braunschweig	1 & 2	Year.	4	6	Descriptive.	Clvil Mech. Elec.
Darmstadt	1 & 2	Year.	4	6	Descriptive.	Civil & Mech.
Darmstadt	3	Wint.	1	2	Descriptive.	Civil & Mech.
Darmstadt	1 & 2	Year.	5	3 win. 4 sum	Analytical.	Civil & Mech.
Darmstadt	3 & 4	Year.	1	1	Analytical.	Civil.
Dresden	1 & 2	Year.	3	1	Analytical.	Civ. Sur. Me. El.
Dresden	1 & 2	Year.	4	6	Descriptive.	Civ. Sur. Me. El.
Dresden	4	Wint.	2	....	Projective.	Civil, Surveying.
Hanover	1	Sum.	6	....	Analytical.	Civil & Mech.
Hanover	1	Sum.	3	6	Descriptive.	Civil & Mech.
Hanover	2	Wint.	3	6	Descriptive.	Civil & Mech.
Hanover	4	Wint.	4	2	Practical.	Civil.
Hanover	5	Sum.	2	6	Practical.	Civil.
Hanover	6	Wint.	2	2	Practical.	Mechanical.
Hanover	7	Sum.	....	3	Practical.	Mechanical.
Karlsruhe	1	Wint.	3	1	Analytical.	Civil Elec. Mech.
Karlsruhe	1 & 2	Year	4	4	Descriptive.	Civil Elec. Mech.
Karlsruhe	3	Wint.	2	1	Analytical.	Civil Elec. Mech.
Karlsruhe	3 & 4	Year	3	....	New synthetic	Civil Elec. Mech.
Karlsruhe	4	Sum	2	2	Perspective.	Civil Elec. Mech.
Karlsruhe	3	Wint.	3	....	Practical.	Civil Elec. Mech.
Liege	1	Wint.	2	....	Analytical.	Mechanical.
Liege	2	Sum.	....	Arranged.	Analytical.	Mechanical.
Liege	1 & 2	Year.	2	....	Descriptive.	....
Munich	1 & 2	Year.	4	4	Descriptive.	Civil & Mech.
Munich	5	Wint.	4	2	Practical.	Civil & Mech.
Munich	6	Sum.	4	8	Practical.	Civil.
Munich	1 & 2	Year.	4	2	Analytical,	Civil & Mech.
Munich	6	Sum.	....	4	Practical.	Mechanical.
Milan	1 & 2	Year.	2	5	Projective.	Preparatory.
Milan	3	Wint.	3	3	Descriptive.	Preparatory.
Miian	4	Sum.	3	10	Descriptive.	Preparatory.
Milan	1	Wint.	....	15	Applications of descriptive	Civil.
Milan	2	Sum.	....	12	Ditto	Civil.
Milan	1 & 2	Year.	....	4	Ditto.	Mech & Elect.
St. Petersburg	1 & 2	Year.	2	Arranged.	Analytical.	Civil & Mech.
St. Petersburg	1 & 2	Year.	3	Arranged.	Descriptive.	Civil & Mech.
Zurich	1	Sum.	3	4	Descriptive.	Civil & Mich.

DISCUSSION.

The Chairman (Dr. H. T. Eddy) stated that the subject was a live one in engineering schools, and that it was important to know how much graphical work should be introduced into technical courses. He hoped the paper, which was a valuable one, would be fully discussed.

Professor Mansfield Merriman agreed with the general propositions advanced. It was his opinion that graphical methods were pretty thoroughly taught in all engineering schools in this country, but not always put down under a separate heading. Graphics is usually taught in connection with the study of roofs and bridges. In his own practice he gave seventy to eighty exercises to the study of stresses in simple trusses, of which about one-fourth were devoted to graphical methods. He urged that the diagrams should be drawn in ink and then be carefully scaled. He said that graphical methods had not come into as general use and prominence in this country as was expected when they were introduced fifteen or twenty years ago. He could not explain the reason, unless it were that the bridges were so largely of one simple type.

Professor J. B. Johnson thought graphics might better be taught in a course by itself without any reference to its applications. He thought the course in geometrical drawing and descriptive geometry could be combined with graphics.

Professor D. S. Jacobus explained that in the institution with which he was connected graphical methods were used in the course in algebra and mechanics, and found to be very useful. He thought there should be a separate course in graphics aside from statics.

Professor R. C. Carpenter gave instruction in graphics in connection with the solution of all theoretical problems, but many times he found difficulty in applying graphical methods owing to the lack of drawing tools.

Professor John Goodman agreed with the author of the paper, and advocated a thorough study of graphics. Such a course is given at Leeds and at the University of London.

Professor O. H. Landreth thought the teaching of graphics of more importance than many appreciate, but advocated teaching the principles and the applications at the same time.

Professor H. W. Spangler believed it the best plan to teach the elements of graphics early in the course and independent of its applications.

Professor J. H. Kinealy wished to know when graphics should be taught. In his opinion, graphical statics could come early in the course, but the graphics that a mechanical or an electrical engineer required must come later.

Professor S. W. Robinson remarked that some use the word graphics improperly as synonymous with graphical statics. He emphasized the point that graphical statics is only a tool by which principles are applied, and that a knowledge of graphics by no means does away with the importance of a thorough understanding of the principles of algebra, geometry, mechanics, etc.

H. Wade Hibbard called attention to the value of a knowledge of graphics in explaining engineering work to uneducated persons, particularly employers.

Professor W. Ritter (a pupil and the successor of Culmann, Zurich) said that graphical statics were probably held in higher regard in Switzerland than anywhere else in Europe. He recommended that the teaching of graphical statics be under the direction of the instructor in bridges. He thought graphical statics very valuable to the engineer, but confessed that the subject was not as highly valued in Europe as twenty years ago it was hoped it would be.

Professor D. C. Humphreys referred to the extended use of graphics in the work of the Mississippi and Missouri River Commissions, for which purpose it had entirely taken the place of algebraic work.

Professor R. S. Woodward thought there was a strong tendency to over-estimate the importance of graphical processes, although he had no intention to disparage the graphical side. Many engineers are poor computers because they have not been taught arithmetic properly, and that is the reason so many prefer graphical methods. The graphical process is frequently compared with a much more exact algebraic method, or with a needlessly laborious one, and the conclusion drawn that the graphical is the best method of calculation. The graphical process has limitations which are frequently overlooked. He thought it should be taught by itself and particular attention be paid to its limitations.

ON ORIGINAL RESEARCH BY STUDENTS IN UNDERGRADUATE COURSES IN ENGINEERING, ESPECIALLY CIVIL ENGINEERING.

By CHARLES D. MARX,

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In the attempt to present the topic under discussion in a condensed form one is met by a serious difficulty, namely, a lack of unanimity in the use of the word "original." One debater, holding to one meaning of the word, may declare himself in favor of original work in the undergraduate courses; another attaching a different meaning to the word, may argue strenuously against such an introduction. The difficulty of classification has not been lessened by the fact that the same difference in the use of the word "original" also exists in lines of work other than our own.

Webster defines original as: *first*, "not copied, imitated; or translated; new, fresh, genuine;" *second*, as "before unused or unknown." If the definition of group one be adopted, calling original something that is "not copied," we can readily come to an understanding, as it will be shown that work of this kind is absolutely essential for the training of our men. If, however, original in our minds, stands for something "before unused or unknown," there will probably be a difference of opinion as to the value of the introduction of such work in the undergraduate courses of engineering schools.

Recurring again to the first definition, it will be apparent at once that all of the engineering schools in this country, which pretend to give their men any training at all, insist on their students doing such "original" work. In the various lines of study, specific problems are given and solved. In surveying, for instance, over and above a mere rudimentary knowledge of the handling of instruments, students should and are called upon to use their knowledge in the solution of larger practical problems. Topographic, hydrographic and even geodetic surveys, extending over limited territories of course, serve to give the men facility in solving the problems of actual practice, which sometimes differ from those attempted in the college only in scope. Again, in the designing of structures, a hypothetical case is given to the student, and he is called upon to embody the solution in a design which, in his opinion, will best meet the stated requirements. Of course, it is not claimed, nor is it expected, that such a design will be in every instance a thoroughly practical one. It is original in the sense given above, and it will undoubtedly have served the purpose of bringing before the mind of the student many of the difficulties which arise in the solution of such problems. It will have set him thinking to find methods for overcoming these difficulties, and in bringing him right up against the difficulties and in setting him to thinking, the object of the course is being accomplished. The student's powers are developed, not brought to fruition.

The college course will start the blossoms, but practical experience must ripen the fruit. It is true that the opinion has been held by a few that investigation and criticism of existing structures, for instance, should take the place of actual attempts at design by students. The holders of that opinion seem to forget that the investigation of the completed structure does not impress the student's mind in the same manner with the difficulties that were overcome in its erection as would the overcoming of some of his own minor difficulties. Again, it must be said, if the student is not deemed competent to attempt the design of even a small structure, how much less competent must he necessarily be to pass intelligent criticism on the solution of a large and complicated problem. A student is justified in making a poor design, if he but do the best he is capable of; he is not justified in passing criticism on a design unless he possesses ability to judge clearly of all the attending difficulties and practical points influencing the designer. These latter do not always show in the completed work, nor can a complete record of them be often kept. Excellent monographs on completed engineering structures, such as those by Morison, Boller, Hutton, and others are the exception rather than the rule in this country. The student, therefore, cannot get the data for forming an intelligent criticism even if his college course would enable him to form one. The right to criticize must be based on the ability to do, and hence the training should tend to develop the latter first.

One might go on to specify every subject taught in our under-graduate courses and show the vivifying effect of such "original" work or research, both upon the student and the teacher. But in such an assemblage as this it would almost seem like carrying coals to Newcastle. We are perhaps all agreed that original work or research as outlined above forms at the present time the backbone of our under-graduate curriculum. It is the laboratory method of teaching which has so largely supplanted the text book.

But if we now pass to a consideration of "original research" as a part of the college curriculum for under-graduate students in engineering, using for the meaning of the word "original" our second definition, namely, something "before unused or unknown," we may probably find ourselves arrayed on two different sides. I will try to state as briefly and as fairly as possible the arguments which can be advanced on both sides and leave it to the discussion by the introduction of new material to determine to which arguments the greater weight should be given.

From the standpoint of the opponent of original research, the following objections may be raised. Owing to the comparatively low entrance requirements of technical schools in this country and the shortness of courses, all the time available is needed to give the men what can be called only a fair grounding in the essential studies underlying the profession. Justified complaints exist as to lack of general culture training on the part of many engineering graduates. These complaints we must remove. We must train our men so that they will be men first, then good engineers. If this demand is justified in any country, it surely is the United States, where we have such a community of duties and interests. More time must therefore be given in our technical under-graduate courses to liberalizing studies. English, History, Social Economy, and Modern Languages must form an integral part of every man's education. The added time for these necessitates more than ever that we confine ourselves in our technical work to strengthening the grasp of our men on the general principles of what are called the professional studies. The method of doing this is the one outlined in the first part of this paper. Original research, using the second definition, would prevent the attainment of this object, for one reason, and would itself be prevented for another. Original research by students can be carried out in two ways; (1) the investigation of the student is part of the larger one which we will suppose is being carried out by the professor. The student in that case may or may not have the power to grasp the scope and bearing of the investigation. In either case his part of the work is likely to consist in the repetition, say, of a number of similar experiments. The facility acquired in performing these experiments, while of value, might as well have been gained in the performance of various experiments tending still further to fix general methods of observation and experiment in the student's mind. Special faculties are developed before general power is gained. If the investigation is of such a character that it can be classed in the second group, that is, original research carried out in its entirety by the student, the objections become still more serious. It will perhaps be admitted that such original research requires on the one hand exceptional qualifications on the part of the student, and on the other exceptional facilities for research. I say advisedly exceptional qualifications, for before attempting any such line of work the student should be thoroughly posted in the whole history of the subject. He should have read and digested what others have attempted along the same line. He should possess the ability to recognize errors vitiating results already obtained, the fallacy of deductions drawn from the results, and in short, have a complete and thorough grasp of his subject from all sides. Can ability such as this be claimed for the average under-graduate student? Can the crude material of the freshman year be shaped into a body of well trained, widely read, logical thinkers, and be inspired with the spirit of originality in the four short years of a half-college, half-professional course? Again, it must be admitted that the facilities for original research, such as this, could be furnished by only a few of the richest technical schools, and even by them along but few lines. Laboratory experiments as aids in training are different from laboratory experiments for practical purposes. This does not detract from their value as aids in training, but it does detract from the value of the practical results obtained. To get this latter, it is now fully recognized that we must have full-sized experiments, experiments carried out under the actual conditions of practice as nearly as may be, experiments which often cannot be carried out except in actual practice on actual structures. This fact is now appreciated by the most enlightened countries. In Germany and France exceptional facilities are placed at the disposal of trained men and original thinkers for carrying out such work. Laboratories for original research, pure and simple, are established and maintained by the governments. In our country private and corporate enterprise have come nobly to the front, and the work of many of the men assembled here this week speaks louder than the writer could in praise of their devotion to original research. But, this work has been done by these men after years of patient study and investigation, after years of practical experience, after a thorough insight into the complexities of the problem before them, and with a realizing sense of the limitation in their practical bearings of the results obtained. Work such as this can only be planned and carried out by master minds. A dividing line may well be drawn between the laboratory for instruction and the laboratory for research. The former should and does form in the best of our technical schools an important link in the chain of instruction. In it independent work should be done. In it the experiments, many and varied in range, should serve to fix principles and teach methods of experimentation. In the laboratory for original research the work done should be of such a character as to come under our definition. To sum up: (1) Original research in the second sense by undergraduate students is, in itself, an impossibility; (2) when carried out as part of the research of a competent person, there is danger of sacrificing the student's general development.

On the other hand, the advocates of original research on the part of students do not admit the truth of the sweeping generalizations of their opponents. They are willing to concede that original work of the highest kind can only be done by master minds, but that a small piece of original work done under such direction is the best possible training a student can have for carrying out subsequently original investigations of his own. They claim that a sense of power comes to the student which no other method of instruction can give and great stress is laid on the valuable inspiration imparted to the student by contact with an original investigator. The advocates of original research strengthen themselves in their position by citing the modern methods of teaching science, history, and language. But, say their opponents, may it not be that again there arises a confusion of ideas owing to the abuse of the word "original"? May it not be, also, that a distinction should be made between the study of subjects and the study of a profession, that a difference exists in the fields of application? How much of the work which along all these lines of study is now dubbed "original" might not more justly be called independent, and thus placed on a par with the laboratory work of instruction in our technical courses. Bearing in mind both preparatory training and college curriculum it will need no special proof to show that for a good deal of the work done by undergraduates, and even graduates, in language, science, and history the word "original" is a misnomer. This, as before said, does not detract from the value of the work of the student, but it may and does lead to wrong conceptions outside of the college. It must be admitted that the opportunities for doing small, detached pieces of independent work which may contribute to the building up of some original piece of work are much more favorable along the lines mentioned than they are in engineering. Furthermore, in some branches of science, in history, and in language, the master mind does its life work in the same place with similar material and the same methods with which the student begins his work. There exists a continuity, if I may so say, between the under graduate work and that of the teacher which cannot be said to exist between the undergraduate work of the engineering student and the work of the engineer in practice. The original work of the scholar can in many instances be done in college; that of the engineer must be done in the world. The test of his originality comes when he is called upon to meet a sudden emergency, to quickly modify existing or developing structures to changed conditions, to find the best solution for any given engineering problem. Such originality can only be developed on the basis of the broadest training, supplemented by years of experience and inherent ability. Give our men breadth, therefore. This does not imply shallowness, because for a high and weighty structure the foundations must be laid both deep and broad. Teach our men methods of research and lead them to do independent thinking, but, realizing the fact that the best fruits are those which ripen slowly, do not try to force them. Ambitious attempts at original research will have such a tendency.

These are in brief the arguments on both sides of the topic under discussion which come to the mind of the writer, who has no desire to appear as an advocate nor to hold such fixed views that they are not subject to change. Other facts will no doubt be added on both sides of the question in the discussion. The fallacy or lack of weight of some of the statements made will be exposed. When the arguments are over and an understanding arrived at, let us hope that something will have been contributed toward the better teaching of engineering in our technical schools.

ORIGINAL RESEARCH BY STUDENTS.

By R. C. CARPENTER,

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It is, no doubt, an open question as to the amount and extent of work of the above character that can be profitably undertaken by students in a college course. There are many engineers who feel that work of investigation cannot properly be done by men who have not completed the preliminary training for professional work. on the general grounds that immature students are incompetent and inexperienced. These feelings are no doubt founded on good and sufficient reasons in many cases, but it is also no doubt probably true, that much depends upon the individual student and also upon the training he may have had, so that it would be unsafe to lay down any general law or dictum which would be applicable to all cases. What the writer has to say must be understood as limited by certain conditions, these being, *First*, the wisdom of requiring students to undertake as a part of their educational work, some branch of investigation or research. It is presumed of course that the student has had the training that would fit him properly to undertake the work proposed. *Secondly*, the probability that the work would be suggested and laid out by the professor so that the part performed by the student will be in some respects subordinate, although in the remarks that follow it may not be so characterized. *Thirdly*, the value of this class of work to the student as an educational exercise, although this will not be discussed at length in the paper.

The object of the paper is rather to set forth the writer's own views as influenced or modified by some years of experience with this class of work.

It will be noticed that the term "research" is used in such a sense as to cover nearly the entire field of "experiment," and is not confined to investigations in which the work is entirely along original lines. While no doubt a great deal of this higher class of work can be and is done in colleges, from its very nature more time is required than can generally be spared in an undergraduate course.

The work that is actually accomplished is in nearly every case the execution of experiments which are systematically planned by the head of the department. This work is here called original research, and it is to this class of work that this paper principally applies. This is original research only to a limited extent, and yet this work will afford ample means of exercising the mental powers, the accuracy of observation, and even the handicraft of the student. Many students will never succeed as observers, and all students need systematic training for such work before they can acquire the habits and methods necessary to obtain reliable results. This preliminary training is of value to all students, whether they apply it in original investigation or not, since it gives them a practical acquaintance with measuring apparatus, a useful application of theoretical principles, and an opportunity of studying the material or machine itself.

All the students in Sibley college, in both electrical and mechanical engineering courses, have a preliminary training in both the physical and the engineering laboratories, for the last two years of the time spent in college averaging four afternoons per week, and this preliminary training, which is useful in many other ways, is expected to make the men so familiar with methods of research that they can take a subject for investigation and follow it through a series of careful experiments to a logical conclusion. The engineering laboratory experiments, after a series of trials, were found to give the best results when arranged in a formal course, which was prescribed for all the students, not however in the same order. There is a special reason for this formal arrangement of engineering experiments, since it permits the carrying out of a system of instruction, in which all the students participate and in which the methods can be given great prominence.

In nearly all the engineering experiments "methods" are of great importance, since the subject-matter or result sought is rarely a "constant of nature," but on the other hand is a co-efficient which will vary to a great extent with the system adopted. This may be made clear by an example. Suppose the subject is the strength of cast iron, it will be found that in this case, the form and size of the the specimen and the method of applying the stress will affect the result, and unless a certain and well understood scheme of testing be adopted, the result will have little value for future reference or comparison. Fixed schemes or standard methods which refer results to well known units, must be largely adopted in engineering experimental work, and students need training in such work before they can reasonably hope to succeed in original investigation.* The list of the experiments in the the regular laboratory course of Sibley college may be of interest, and is as follows:

JUNIOR YEAR.

FALL TERM—*Strength of Materials:* Tensile and transverse tests. *Calibration:* Steam guages, indicator springs, weirs and water meters, thermometers, pyrometers, dynamometers. *Experiments:* Flue gas analysis, air thermometer.

WINTER TERM—*Strength of Materials:* Compression and torsion. *Lubricants:* Co-efficient of friction, viscosity. *Steam Engine:* Calorimetery, indicator practice, heating values of fuels. *Calibration:* Planimeter, indicator drum springs.

SPRING TERM—*Strength of Materials:* Impact, Keep's tests of cast-iron, cement tests. *Lubrication:* Flash and chill test, durability. *Efficiency Tests:* Water motor, steam pump, steam engine.

SENIOR YEAR.

FALL TERM—*Strength of Materials:* Elastic curve, brick, stone and cement. *Steam Engine:* Valve setting, Hirn's analysis of simple engine, efficiency test of compound engine. *Efficiency Test:* Gas engine.

WINTER TERM—*Efficiency Tests:* Injector, triple expansion Corliss engine, hot air engine, oil engine, turbine water-wheel, wind-mill, water engine.

SPRING TERM—Regular work not required. Nearly the entire term is devoted to special research and investigation, which is embodied in a thesis.

Note: Students work as far as possible in groups of two.

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*The writer has prepared and published a work on *Experimental Engineering* (J. Wiley & Sons, N. Y.) in which full directions and standard methods, as followed in Sibley college, are given.

The student should have also a training in underlying reasons and principles, or class-room training, and should also take the needed course of reading to attain familiarity with the state of the art.

The college equipment needed consists of the experimental plant, the library, and the force of instructors. A short discussion regarding each one of these will perhaps be in order.

First as to the plant. The amount and character of this is open to discussion. How much is needed depends largely on the subjects which are assigned the students; often very little is required and that can designed, built, and standardized, by the student himself. A large equipment is not usually of special advantage in this work, for the reason that special apparatus is usually required and aside from a few general instruments of accuracy much must often be built specially for the work in hand. The apparatus that is needed should be principally in the form of accurate standards, and measuring and testing machines, and the cost of such machines is usually not excessive. The question of expenditure for material on which to experiment, is one that should be seriously considered. An almost unlimited amount of money could be expended in this way, but usually material and appliances can be obtained from manufacturers interested in the results, for a merely nominal sum. In investigation and research, the obtaining of subjects must depend largely upon outside opportunities. As an illustration, which may perhaps be of considerable interest in mechanical engineering schools, there is the question of how far it is profitable to purchase large engines for experimental purposes. The engines which are now being put in for such purposes are in many cases of great size, they occupy much room, must be handled with extreme care, and can only be operated at very great expense. The question will certainly arise respecting these engines, as to whether the results which are obtained can be applied to engines of ordinary construction, running under the usual conditions, for it is certainly true that these engines differ in many respects from the ordinary type. Their value to a large extent depends upon the readiness with which the surrounding conditions can be varied, and consequently they are built with accessories which are not necessary in ordinary cases, and which render them in many respects very complicated, and in some respects uneconomical, types. The value that investigations on such engines will have upon future engineering practice is certainly an interesting question.

Much could be said regarding the proper equipment for original research, but in general it may be said that it is not the belief of the writer that it is profitable to tie up a large amount of money on subjects of investigation unless they cover such types or machines as cannot be found readily elsewhere.

The question of the amount of instruction which should be given students who are prosecuting research is one also open to discussion. It is probably true that the instruction provided should be sufficient to see that correct methods are used and careful observations are taken. Certainly it would be injudicious to permit students to waste time for the want of proper information in these directions. The students should also be required to carefully look up references in the libraries on the subjects to be investigated.

The time in a college course which can be devoted to such research is in every case limited and it is an important consideration to know at what time such work can profitably be undertaken. In most colleges a portion of the senior year is all that can regularly be devoted to this class of work, and the results of this work is embodied in a graduating thesis. Post graduate work naturally and profitably can largely be in this field.

In the laying out of work of "research" it has been the custom at Cornell for the professor to present a list of subjects, from which the student usually selects one to which he has a liking or which suits his taste. The pupil is required in each case to make a full statement of his proposed work, with a synopsis of his thesis, and he is not permitted to undertake the work unless there is some probability of success. It has been found, however, by experience that it is not always possible to tell in advance whether any given investigation will or will not succeed. Even the best students, using the most careful methods, often lose weeks of work through no fault of their own. Such things cannot be guarded against, for the very nature of the work makes it impossible to foretell what the results will be, unless the student is working within lines which are well mapped out, and with which the teacher is especially familiar. The difficulties which arise and which prevent successful investigations are of varied character. They are often due to the fact that the machinery under investigation is not perfect in construction, or that the apparatus which has been specially employed does not properly perform its function. In every complex investigation, such difficulties are constantly arising, and it is to be expected that a certain proportion of the "research" work undertaken will not arrive at a successful issue.

It often happens that the subject selected is one altogether too extensive for the allotted time, and in such a case the only remedy apparent is to continue the investigation year after year. At Sibley College it has been frequently necessary to adopt this plan, and on the subject of steam-radiators, injectors, coal calorimeters, etc., investigations have already been continued with different student observers for three successive years.

The character of the report made by the student is one of very great importance, for it does not matter how well the experiment may have been performed if the record has not been properly made and preserved. This report should contain in a formal way: *first*, a distinct statement of the object; *second*, a deduction of the principles; *third*, a description of the apparatus, including the methods of standardizing and of using; *fourth*, a log of the results, which should include every figure taken during the test; *fifth*, the averages of the results and their proper collation; and, lastly, the conclusions, which are often of little importance. So far as practicable, graphical methods are to be employed in recording both the results and the engineering laws which may be deduced.

The fields of research are numerous, and include subjects from nearly every conceivable industry. The following list is merely suggestive, and is not intended to be complete or very comprehensive:

Strength of materials, hydraulics, transmission of power, friction and lubrication, steam boilers and engines, hot air and gas engines, air compressors, dynamo machinery, electric motors, measuring machinery—including dynomometers, indicators, gauges, meters, etc.

Another method of classification, as to the field of use, might be made, as follows: Standardization or testing of apparatus, properties and strength of materials, efficiency tests.

VALUE OF STUDENT WORK IN ORIGINAL RESEARCH.

The writer's own opinion of this work is, in general, high, and he thinks it may generally be considered not only good for the student, but as often adding valuable facts to our stock of knowledge. Colleges possess special advantages for such work, as they can generally command a corps of disinterested and skilled observers who care only for scientific truth, and the apparatus at command is usually complete, of excellent character, and better than could be provided by private capital. The methods adopted are quite certain to be such as to be free from criticism. The advantages possessed are such that all conditions can be fulfilled, since financial considerations rarely intervene. No precaution to insure accuracy, in fact, need ever be neglected.

In conclusion it may be said that it is certainly true that in the past, investigations of the greatest value to the engineering public have been conducted by students under the auspices of college instruction. It can be confidently predicted that the superior equipment of colleges and the better training of instructors and students will lead to better work in the future than has been done in the past. It is believed that in the future, as in the past, many of the engineering coefficients which are to be determined, and new engineering laws which are to be developed, will have for their foundation the original work done by students in engineering colleges.

DISCUSSION.

Professor D. S. Jacobus thought probably the author of the paper had referred to him when he said that his paper had been brought out by a criticism that had been made on the subject at the meeting of the Mechanical Engineers. The point there raised was that it is not wise to put up an apparatus to assist in instructing students and then consider that the results of the students' work are good enough to plot down to determine some physical law. Of course in exceptional cases the student may be entrusted with some original work; after he has worked some four months and has thrown away all his work, he may have come to the point where his work is of value. But when it comes to rushing through a lot of students and trying to deduce some law from the results, the speaker did not think it could be done. In all the commercial work done by the speaker and his associates they never trusted the obtaining of the data to the students. They have a special corp of assistants who have been employed for years, and they find it is a regular trade to be able to note everything aright and practically never make a mistake. Again, in obtaining this data the ones that are most likely to make mistakes are not the dullest ones, because if a man is thinking too much he may make more mistakes than another man who only thinks just about enough. The speaker gave an instance where an ignorant Irishman was found to be absolutely reliable in counting the strokes of an engine where more intelligent men would always make mistakes. It don't follow because a man is brilliant he is never going to make a mistake. He considered it a regular trade to take all the data, and he had special assistants who were used to that class of work, and in whom he could place a great deal of confidence, but if you undertake to have a party of students do work which they are not used to he thought it very risky business.

Professor H. W. Spangler wished to say a word about original research by undergraduates. Professor Marx had said in effect that the results are reliable because we have competent observers and because the apparatus is complete. Those who practice engineering in addition to their college work realize that there are few who have the capacity to set up apparatus and carry out a series of experiments. The speaker believed that in the short time in the latter half of the senior year it is practically impossible to do this sort of work. It can be carried on from year to year, but where are the students? It is not a research by the students, but observation by the students. The students are a set of observers and it is simply out of the question to put any credence upon results based upon experiments of this kind. He had had some little experience and it would be a very unusual case where he would put a corporation representing $200,000 into a line of work as the result of a series of experiments carried out in any educational institution that he knew of, and he believed that any corporation that had a large amount of money to put into an experiment would not undertake to do it on results reached by a class of students. He could not think any one would be willing to put credence in results arrived at in that way. These young men do the best they know, but they don't know how—it takes time.

The speaker wished to say a word as to the necessity of liberal study in connection with engineering work. Our engineers go into positions where they meet men of liberal education, men who can talk of other things besides engineering and talk it well, and he thought that many of our institutions are making a great mistake in cutting down the liberal portion of the students' education. He did not mean to say the study of engineering is not liberal in its way, but in a broader sense we are cutting it down so that our men are going to work in a very narrow field and they will get into a small rut in a few years. It seemed to him that the course of work outlined by Prof. Carpenter left the experimenting to skilled observers, not to engineers. But the business of an engineering institution is not this class of work. It was evident that if under his direction a series of experiments are being made, if he was responsible for that work, he proposed to see that the work was carried out in the right way; these men were to do what he set before them. If he was to be responsible, then he would simply drill those men, he would have them do the work he wanted them to do in his way. He could do that in such a way that they would get the idea that they were doing it, but the fact would be that if he had to give an engineering opinion on that work he would not take the results of others, he would take their observations and satisfy himself first that those observations were right. Beyond that he was responsible and it was his work, not the work of his students. Therefore he would be developing men to become observers, or experimentalists, in a very narrow sense. It seemed to him this course of work was strongly in that direction, and therefore, he thought, unfortunate.

In research work by students he had a very distinct idea as to what he wanted to accomplish. He wished to make all the men alert, quick, sharp, exact, and to develop if possible their engineering sense. That is all. He had no other object in the research work that he carried out than those three things. If he could do that, he had given them a broad enough foundation, he believed, to make good engineers in the future.

Professor Carpenter was not sure that he differed particularly from Professor Spangler. He did distinctly believe, however, everything stated in the paper. He agreed with Professor Spangler that research work should not be undertaken until the student had had two years' practice. If, after two years' practice, a man is not a skilled observer, if his opinions are not worth anything, where will we find them? Students are bright as a rule, they are well trained for the work, and the work they do is good, much better than that done by outsiders. The laboratory exercises are arranged with the idea of making the students more intimate with the laws of forces and materials. The under-graduate laboratory, as we conceive, it is not run for the mere purpose of making observations, but to give the students greater familiarity with the machines, giving them an opportunity to handle and study the machines, which they cannot get from text-books, and the result is that after they have had that course they go out into the world very much better prepared to meet the problems of engineering life, very much better equipped.

The speaker had not referred to Professor Jacobus in his paper, and he perfectly agreed with him, and some experience of his own had been exactly in accord with that of Professor Jacobus. He never yet had been able to utilize that work and did not see how it is possible to arrange such work so as to be available. However, he did not refer to that class of work. He might say that in several instances with under-graduate work, for instance in investigating the properties of materials, the strength of different kinds of materials, he had found that such results could not generally be relied upon, that the different individuals obtained different results. It is no doubt true, and must always be true, that a large portion of original research must be guided distinctly by the head of the department; that is, it must be planned, must be looked after, and every precaution must be taken to make sure that the results are accurate. As to the conclusions which are to be drawn from such work and which are of course important, he thought just as Professor Spangler did, that they should all be drawn with extreme caution. The investigations must be carried on by some one at the head of the department, with the students' help, and that help is only valuable after it has had considerable training.

FIELD PRACTICE AND FIELD EQUIPMENT.

By C. D. JAMESON,
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The teaching of the practical details of any branch of engineering during a four years' course, is an impossibility in most of our engineering schools, and is not desirable in any.

These details of practice can only be properly taught by experts, and none of our schools have sufficient money to employ experts in each branch. Then again, if there was sufficient money, this detail practice could only be taught at the expense of some of the general principles, the lack of knowledge of which would be a much greater loss to the student than any gain he would get by the study of the details of practice. Another objection to the spending of much time upon the details of practice is that, in this age of continual change and progress, the chances are that long before a student will have opportunity to apply this so-called practical knowledge, the acquiring of which has occupied a large proportion of his four years' course, the details of practice will have entirely changed, and he finds himself not as well fitted for his work as the engineer who devoted the most of his four years to the study of the so-called theory of engineering. The only instruction in practice that the student should receive is such as will enable him to do the work he will be called upon to do during the first year or two following graduation. This work of course will in all probability, be of the most elementary character, but he should be able to do it in a rapid, thorough, and workmanlike manner. Not as one who requires instruction as to methods, but as one who is thoroughly master of the methods and details of practice; who has simply to have what work is required specified, and then, without any further instruction, be able to go ahead and do it. The student in engineering can only advance in his profession after graduation by constant work under men who are experts in their lines, and these experts are not going to give employment to young men who cannot make themselves useful and, to a certain extent, valuable to them from the start.

It is in every way desirable that the engineering student should go to work within a short time after graduation. The majority of engineering graduates are obliged to do this from financial reasons, as they have either earned money with which to pay their college expenses year by year, or else have borrowed it and are obliged to go to work in order to live and pay their debts. But whether the financial necessity exists or not, the student should go to work at once. He has acquired the habit of mental labor. The principles of his profession are fresh in his mind, and after a few month's rest, he is in better condition to commence his work than he will ever be again.

In order to commence work he must obtain a situation, and to do this and to hold it he must be able to render himself of value to his employer. The work that he will be called upon to do will be of the most elementary character, but he must be able to do it well and quickly. Quickness with accuracy are two things that each young engineer should strive for, and the practical training the student should receive in college is just that training which will enable him to do in a satisfactory manner this elementary work.

If proper attention is given to the the theory of engineering there will not be time for the study of more than elementary practice, and for the study of this elementary practice time should be taken, as without it the student is handicapped one or two years.

The remaining pages of this paper will be confined to the field practice that should be given to the civil engineer.

First. As to the amount and character of the work.

Second. As to the methods of instruction that should be used.

Third. As to the equipment necessary for the proper giving of this instruction.

What follows is based upon this fundamental idea in regard to collegiate instruction in field practice, or the practical details of engineering, viz.: Owing to the fact that the standard course in civil engineering is only four years, the amount of time devoted to instruction in practical details, or field practice, should be just sufficient to enable the student, upon graduation, to do well the work he will, in all probability, be called upon to do during his first year or two of practice, and the remainder of the four years should be devoted, as far as technical instruction goes, to the principles and theory of engineering.

First. The character of the practice given should be such that the student should be a rapid, accurate draughtsman, thoroughly conversant with the standard methods of keeping notes of all kinds and be able to express clearly either his, or someone else's ideas upon paper in the shape of plans, elevations, and sections, in such a manner that they can be clearly understood, with a minimum of written explanation. No time should be wasted upon fancy drawing or lettering but the student should be trained to accuracy, rapidity, neatness, and an ability to work out all his ideas on paper, with a certainty that if his drawings are accurately followed in the actual work the desired result will be attained.

It should be remembered that good draughting does not consist merely in a certain amount of manual dexterity with drawing tools, although this is necessary, but that good draughting consists in working out ideas accurately on paper; for instance, take the idea of a complicated machine—the draughtsman should be able to make plans for each separate piece of mechanism, and so develop the whole machine on paper that he can know before the machine is built exactly how it will work, and what it will do. His plans, elevations and detailed drawings should give him just as comprehensive an idea of the future machine as he could get from the actual machine when constructed. To acquire this ability of solving all such problems by drawings, requires not only a training in the manipulation of drawing tools, but also a mental training in the reading and understanding of plans.

The use and adjustment of the ordinary field instruments should be thoroughly taught. This should include the aneroid, altazimuth, pocket compass, surveyor's compass, transit, level, solar attachment, and plane table. The capabilities of each instrument should be thoroughly understood together with their construction and adjustments, and sufficient field practice given to allow the student to not only know how to use them, but to be able to use them rapidly and accurately.

There should be sufficient practice given in land surveying to enable the student to have a working familiarity with all its details. In railway location some time, but not too much, should be devoted to the theory, while the details of actual work should be thoroughly taught. The graduate is not expected to be able to select the best line for a railway between any two points, and establish the grades, etc., but when he has the general direction and position of the line given him, with the limiting curves and grades, he should be able, without further instruction, to put that line on the ground and make a plan and profile of it.

In order to do this in a satisfactory manner he must have actually done this class of work before under careful instruction as to the work required, the data to be obtained, and the detailed methods of obtaining this data.

The location of the line is followed by topographical work Then the final adjustment of the line to the ground, the setting of the slope stakes, and the estimating of the amount of material to be moved, and masonry, etc., to be built. This should be worked out in all its details during the four years' course. The instructor in field practice should remember that his object should be not to give the student a superficial idea of a great many things, but such a thorough drill in the actual details of such points as he does take up, that when the student goes into actual work the methods to be employed in elementary practice have become to a certain extent automatic, and no thought is required excepting as to the ultimate results to be obtained. If necessary, let the field instruction cover less ground, but have the details that are taken up thoroughly drilled into the student. As an example of the error which in the writer's opinion is made in many of our engineering schools, in which he believes most engineers on maintenance of way will bear him out, is the fact that the average graduate during the first year of his work has perfect confidence in his ability to calculate the strains and make the detail drawings for the most complicated frame structure, while it is utterly impossible for him to locate correctly a side track and stake out the position of a frog. What should be done is to devote more time to *advanced* theory and *elementary* practice, and less time to so-called *advanced practice.*

The student should also receive sufficient instruction in the use of the various standard testing machines as to render the different methods of testing the materials of engineering construction familiar to him. This laboratory instruction should be given in connection with the lectures upon these materials, and he should be taught not only the manipulation of the machines and the methods of testing material, but should also be sufficiently familiar with the nature and use of the different materials to know for what properties each should be tested.

In regard to the amount of time necessary for this practical instruction, much depends upon the instructor. But with very few exceptions, much mere time is devoted to this class of work than there is any need of. There are two reasons for this: first—a catering to the public cry for so-called practical instruction, and the fact that the students are much more enthusiastic in this field work than in purely theoretical work: and, secondly—it would seem that an unnecessary amount of field practice is sometimes given students from the fact that such work requires no preparation on the part of the instructor, and he is therefore tempted to increase the time devoted to work that more or less consists of manual dexterity at the expense of the more advanced theory. The following allotment of time has been found sufficient in the writer's experience and it probably could be shortened to advantage.

The use and adjustments of the various surveying instruments, not including the plane table, in the spring of the freshman year. Land surveying in the fall term of the sophomore year. Mapping of the notes during the winter, and topographical work and use of the plane table in the spring. Railway location in the fall term, junior year, with the preliminary plans and profiles. The final plans, profiles, estimates, etc., during the winter, together with lectures on railway construction and materials of construction; with railway yard work in the spring.

As to the number of hours per week that can be devoted to this work, the writer has found that four hours each Tuesday and Thursday afternoon, and eight hours on Saturday was amply sufficient. This time does not mean actually sixteen hours per week, as much time in the spring and fall is lost for field work by inclement weather. Any of this field work can be carried on to much greater advantage to the student if it is possible to take the class into camp, on railway location for instance, for two weeks. This, however, is seldom possible during term time, and in the west is impossible during the summer vacation, owing to the fact that the majority of the students are obliged to work during the vacations in order to earn money to pay the expenses of the next term.

In regard to methods of instruction in field work:

We will suppose that the student understands the use and adjustments of the instruments, and to some extent has studied the theory of surveying and elementary field work. In this field practice it is in every way advisable that some definite problem should be given the students to work out in all its details, in order that they may get not only the methods required in each class of work, but also that they may understand the connection that exists between different branches of field work. In surveying the writer has found it a good plan to take a full section of land and have a thorough survey made of it, running the full section lines, the quarter section lines, and then the property lines—the name of each property-owner being taken. Notes should be taken showing the state of cultivation of each piece of ground and when the maps are made all of this should be shown by conventional signs. This surveying is usually done in the fall and the notes are platted during the winter. In the spring, before the leaves are out on the trees, a certain amount of practice should be given in triangulation, and then the section that has been surveyed should be contoured by means of the stadia and plane table. There is ample time to plat all of this topographical work before the close of the school year.

The advantage of confining all this work to one piece of ground is that the students become thoroughly familiar with this section. They can accomplish more work, and work of a better character, than if they are changed from one piece of ground to another. They have a definite object to work for, outside of the mere practice in the different branches of surveying, and know that when the work is finished they will have complete evidence of everything done. In no other way can the standard of work done by students be raised and the amount increased so easily as by so arranging it that the student can see that in the end he will have obtained some tangible results of more or less value, in addition to having obtained the requisite amount of practice.

In regard to railroad work the students should be given practice, not only in railroad location and the details of laying out new work, but should also have practice in re-running old lines, re-establishing the grades and centers, and in laying out yard work.

In railroad location the general principles should be explained fully before the field work begins. In selecting a section of country it is advisable to take two towns, ten or twelve miles apart, and have the student make a thorough reconnoissance of the country between them. The methods used should be similar to those used in actual practice, and there should be a time limit in all this work to which the student should be strictly held. Each student should present a written report with sketches of the country and give clearly his reasons for considering any one possible line better than another. The preliminary line should be run, and each day's work platted that night. This preliminary line should be run the whole of the distance between the towns and preliminary estimates made. A final location of two or three miles is usually sufficient. After the final location has been made, slope stakes should be put in and final estimates, with plans, profiles, and a written report as to probable cost, etc., made.

Although only land surveying and railroad work have here been considered, the same principles apply to sanitary, hydraulic, or any other branch of engineering.

In regard to field equipment, it is not necessary to go into details as the equipment required depends entirely upon the character of the work done, and any person capable of preparing a course of instruction in Civil Engineering can experience no trouble in making out a list of the instruments necessary for the proper giving of this instruction. There is, however, one instrument for field work that has never been appreciated by American engineers, either as practicing engineers or as instructors, and that is the plane table used with a telescopic alidade containing stadia wires. One reason of this non-appreciation of the plane table is due to the excessive weight and faulty construction of the earlier types, but during the last six years plane tables weighing no more than ordinary transits have been upon the market, and constitute a most valuable instrument for topographical and preliminary work.

In instruction in field work care should be taken that the student gets the correct idea of the relative amount of refinement required in the different operations, so that he may not waste time in calculating earth work to three or four decimal places, but that he may also understand what operations need excessive refinement. In conclusion, it may be said that in our Ameriaan schools of engineering with only a four years' course, the amount of time devoted to field practice, or instruction in practical details, should be limited to the minimum amount necessary for correct instruction in such elementary practice as the student will be called upon to do immediately after graduation, and the remainder of the time should be devoted to the thorough understanding of the general principles and theories that form the foundation of the art of engineering.

DISCUSSION.

Professor Monroe gave an account of the field practice work in surveying at Columbia College. The work was formerly done in New York City, and through the co-operation of the Central Park Commissioners, was done in Central Park during term time. The park offered a very fine field for the work, a great deal of variation in topography, and an admirable chance for instruction in the various branches of engineering. It was found, however, that there were several objections to doing the work in term time, and doing the work so near a large city, and especially in a finished park, and after six years it was decided to abandon the work there and to try to do it some distance from town in the country. It was found this could be done by using express trains, running to a near point with no greater loss of time than had been incurred in doing the work in Central Park, and with very great advantages, in that the work was not interfered with by others. It was found, however, that this plan did not overcome all the difficulties.

The chief objections that were found in doing work in term time were, first, the loss of the students' time in going to and from the work; it would take from half an hour to three-quarters of an hour to go and come, and of course that was a very large slice taken out of the afternoon. Of course, the conditions are peculiar in New York City, and colleges in the country would not have the same difficulty. There is, however, another objection which applies to doing work in term time, which is common to all schools, and that is the fatigue of outdoor work in the afternoon, especially to students who, perhaps, have been working all the winter over their books, the fatigue and exposure to air and wind and sun in the afternoon produce a heavy, drowsy, sleepy feeling in the evening, and the result was that the work of preparing for the next day's recitations was very severely interfered with by this afternoon work. There were many other reasons which led to the next step, which was to place the surveying in the summer, and to do the work at some distance from New York in a cool, comfortable locality in the Berkshire hills of Connecticut. The work went on there for some seven years in the vicinity of Litchfield, Conn., and on ground that was given for our use by some of the residents. They permitted us to make use of their property for surveying purposes. Fortunately Litchfield is in a dairy country, there were very few crops to be interfered with, the work was done in the last part of the summer when the only crop, the hay crop, had been harvested, so that the work could be done with very little interference.

The advantage of moving to the country was felt at once. The students worked from seven or eight o'clock in the morning until dark, often taking their lunches into the field with them, so as to work continuously, and they would accomplish more in a day than they would in nearly a week under the former conditions, because their work was uninterrupted. In a day you can get eight or ten hours of uninterrupted work, whereas, when afternoons of term time were used, what with the loss of time in going to and from work, setting up instruments and putting them away again, one would hardly have an hour and a half or two hours available time in the afternoon; so that a day in vacation is almost equivalent to a week of afternoons in term time. Of course, Saturdays under the plan of doing the work in term time would count a full day. Another advantage of doing the work in summer was that it was possible to require accurate work on the part of the students, the stakes not being interfered with, the students having plenty of time to do the work, there being no interruptions or loss of time or loss of stakes, it was possible to keep the students up to a very high degree of accuracy.

Finally the next step was taken, the last step, and that was to rent a farm, and now Columbia College rents a farm of about one hundred and twenty-five acres, which was chosen for its topography in order to give as great a variety of surface as possible, and on this farm now all our surveying work is conducted. We have a lease of five years with the privilege of five more, practically ten years, and we shall probably buy the farm at the end of the lease as a result of our experience. In regard to the work itself there are two or three points that as a result of this seventeen years of experience have developed themselves, which are somewhat peculiar, and which characteristics have been found essential to success. In the first place the squads of men are limited to two. There are never more than two men at one instrument, even the plane table. The great advantage of that is that each student has abundant opportunity to become familiar with the instruments. Where squads of five or six men are together, one man out of the six will do most of the work, and the chances for each man getting at the instrument are only one-sixth of the total time, and the probability is that one or two students will absorb the greater part of the time, and the others will permit it. Again, with large squads it is much more difficult to maintain discipline. Not more than two students can be kept busy at once. A student who is unfamiliar with an instrument cannot keep more than one assistant busy. With squads of two men they are kept very busy, and they have abundant use of the instrument. So far as practice is concerned, it may be said that a day where there are only two men on the squad is equivalent to a week where there are six men on the squad.

The next point is that everything is done to insure economy of the students' time. At Columbia there is a large force of assistants, and the work is so subdivided that each assistant has charge of a few squads only, and can visit these squads at frequent intervals. While the student is made responsible for the work and the accuracy of it, he need not lose time because of any uncertainty as to the best methods of carrying on the work, because the assistant is always near to give advice. Where accuracy is required, of course there is the danger that the students will resort to dishonest practices in order to obtain the desired accuracy without doing the work. This of course is fully appreciated and has been guarded against very carefully, the principle being to make it a little more difficult to do the work in a dishonest way than to do it properly, and to remove as far as possible all temptation from the student to do work of this character. For example, the line of levels laid out over which all the squads have to run is a mile in length with stations every one hundred feet, and with bench marks every five hundred feet. At each station where there are bench marks there are placed some six or seven benches, the levels of which are known accurately, and at each station there are six, seven or eight plugs driven in the ground, the elevations of which are known but which are changed from time to time. It is evident that by starting squads from different benches, giving them the same datum, but really a different elevation, and by obliging them to check on different benches along the line, and to use different stakes, the permutations and combinations of this single line of levels are almost infinite and the trouble of computing a theoretical line of levels along the route given is so great as to deter the pupils from doing it. Even if this were attempted it would be an easy matter to detect it. It has been found by careful determination of the result that there is a certain law of error, so to speak, that is that errors, unless gross mistakes are made, tend to increase or decrease pretty regularly, and by simply finding out what are the errors as determined from the average of the levels given, by determining the errors you can tell by inspection very quickly whether the work has been honestly done or whether it has been done by some dishonest method. A similar plan is followed for the traverses. There are on this farm some one hundred or more stone monuments which are placed about two hundred, two hundred and fifty, or three hundred feet apart, on the corners of a series of quadrilaterals, making a large number of quadrilaterals covering about half the area of the farm. These stones are placed in the earth. In the center of each monument is a copper bolt and the center of this bolt is marked by a small center punch. At the cost of a great deal of labor all the distances between these monuments (and there are a great many hundreds of them on the sides and diagonals of the quadrilaterals) have been measured with a steel tape, so that the distance between these stations is known probably to less than one-hundredth of a foot even in a three or four hundred foot course. The angles also between the different lines at the intersections of the quadrilaterals have been determined very carefully, so that the angles are known to a probable error of about four or five seconds. Each year these measurements are repeated so as to tell whether the monuments have shifted, and the shifting monument again is a deterrent to an accumlation of data for dishonest purposes, so that each year we know just what the distance is between these monuments.

Again, the lengths of the tapes which are used by the student are determined. The measurements are made with tapes three hundred feet long, by a method introduced by Mr. Cox, of Pennsylvania. The error of each one of the tapes given out to the students is known. The students do not know these errors, consequently if they should use some other tape or the measurements obtained from some other tape, they would obtain results which would not agree with the results which ought to be expected from that tape.

Again, the limits of error in the students' determinations are accurately known, for these can easily be determined from the measurements of the same distance by different squads, and if there has been any collusion by the errors being abnormally small, or the distances before being corrected being the same, and after correction very different, the fraud can be detected.

The great advantage of this system which has been followed is that the students are checked, not on finished work, but on every measurement that is taken, on every reading of the level rod, on every measurement of length, on every measurement of angles.

The student is required to make preliminary reports on the work that he has done during the day, and if it is found that there are two or three measurements that are wrong, he is required to repeat double that number. If as many as half the measurements on a traverse are wrong, he is required to repeat the whole traverse. Before they have gone too far with inaccurate or improper methods, the instructor is enabled to correct their methods of work, and to insure that they shall adopt, the next day, proper methods.

Again, the students are not permitted to repeat a measurement of any kind more than three times. The first time that an incorrect measurement is reported, he is required to have an assistant present when he repeats the measurement once, to make sure that the proper method has been adopted the second time. If an incorrect measurement is reported a second time, the professor himself generally tries to be there when the third measurement is made. After that, the student is not permitted to repeat it again. This avoids wasting the student's time, for it may be, of course, that the error may be due to the instrument, may be due to the rod or the tape, or it may be an error in the original determination of an elevation or distance or angle, as the case may be.

Now as to the course adopted in surveying. The course begins with a pacing survey. The student is practiced in determining the length of his pace. The natural pace is first determined on level ground, then on sloping ground, up and down hill, and from the results of this determined natural pace an artificial pace is assigned him, slightly shorter than the natural pace, and with this artificial pace he makes his measurements. It has been said that it is desirable that students should always use their natural pace in surveying. This, however, is impractical because the natural pace varies so. In going up or down hill some people lengthen and some shorten their pace, but even if they maintain the same length of pace the measurement would have to be reduced to the horizontal and a different correction would have to be applied to every different degree of slope, but by accustoming the students to take a pace a little shorter than their natural one (suppose their natural pace to be two feet seven, let them take a pace of two feet five), and they have one then that they can maintain under all circumstances. In going over level ground they would shorten their pace a little; in going up hill they would take their natural pace, which is equal to an artificial pace on horizontal ground. If they are going up a very steep place they would take a stick, perhaps, and measure the distance on the ground. It is found that this method gives a higher degree of accuracy in pacing than where an attempt is made to use the natural pace, or where an attempt is made to use a very long artificial pace. The pacing survey is the introduction to determining the points of survey, and by it a student is taught to make many measurements. By pacing, the measurements can be made very rapidly, and the student can learn a great deal in measurements by a very little loss of time. The pacing survey is followed by a topographical survey in which the pacing survey is made with a level. Then he goes to farm surveys, and he learns to read all the bearings. Then comes the compass survey, after which the more accurate instruments, the transit and the level, are taken up. At first the instruments are thrown entirely out of adjustment; the student is required to adjust them perfectly. Then every morning before the student goes out to work he is required to run over the adjustments, make sure that the instrument is in good adjustment, and the result is that the student becomes pretty familiar with the instruments. The first exercise is the measuring of angle work by repetition. Known angles are taken and the students are required to measure these angles by repetition, making a large number of repetitions and determining the angle by dividing the last reading by the number of repetitions. This of course gives the result more accurately than measuring the angle singly, and as it has been already measured by more accurate instruments, the instructor is able to check the angle measured by the student.

Without going farther into details, it is the aim all through to make the course progressive, and to make sure that the students use correct methods from the very start, believing that if a student is allowed to go on with incorrect methods a day or two, it is very much more difficult for him to unlearn than to do it correctly in the first place. In all the traverses the purpose is to obtain the highest degree of accuracy, since less accurate methods can be easily learned by students, but he may not have an opportunity of learning more accurate methods in later life. In the traverse the students are required to repeat the angles, making several repetitions. Of course other methods of traversing are given, as with the telemeter, with continuous readings, etc.

One of the most valuable instruments used in the work, which has been used for seventeen years at Columbia, is the plane-table, already referred to. This instrument is rarely used by engineers in the field, but as a method of instruction it is very valuable, teaching methods applicable to other instruments, providing the student understands them and has already used them in other instruments. Every student is required to make a survey of something like one hundred acres with the plane-table, putting in contour lines twenty feet apart and determining a very large number of points.

A hydrographic survey is made with a preliminary triangular survey and a large number of soundings; similarly with the mining survey and finally the railroad survey.

PROFESSOR BURTON thought that this question of economizing time in surveying was especially applicable just now. There is no place in the school course where time is more easily wasted than in trying to give adequate instruction in surveying. In the Institute of Technology of Massachusetts they are surrounded by just the same circumstances as those at Columbia College. They are in the city, and find it difficult to carry on surveys in the immediate vicinity, and the evolution there has been on lines similar to those in Columbia College. In the details of vacation work, however, they had had somewhat different experiences. He would first describe the way in which they had tried to meet the question of teaching surveying during the school year. In trying to economize time they had found that two things are very essential; first, that whatever weekly period is given to field surveying it should be continuous. They had done this by taking a day for surveying. This gives five hours continuous work. This day is so arranged that the next day's work following will be of a character that will not be affected by the fatigue of the students of the previous day as much as would ordinarily be the case. They also find that they can so arrange this day that when the weather does not permit of surveying, the time can be utilized without any loss in the regular routine of instruction, in the mathematical part of surveying, or in drawing. He placed great stress on this point, because he thought it was not brought out fully by Professor Monroe, that by putting the time together, whatever hours you have, you can manage to give during the school year much more instruction for the given number of hours than in any other way. He found by the tables given by the *Engineering News*, that the Institute of Technology gives about the minimum amount of time to surveying. He thought that they give fully enough. In the paper by Professor Jameson he found the time mentioned there as greatly in excess of anything they had ever thought of at the Massachusetts Institute. They find there that two hundred and forty hours in the whole course is sufficient, that five hours a week is ample to give instruction in the use of the simple surveying instruments, that is, the more common surveying instruments. The instruction in pacing, the instruction in the use of the chain, the compass, the transit, and the level could be given during the second or sophomore year of a civil engineer's course in one hundred and eighty hours, and even in a large city when it is necessary that a train should be taken by the students in order to convey them to a suitable location. Their experience had led him to believe that by arranging the work properly, this amount of time is sufficient for those studies. The most important consideration is the smallness of the divisions at the work and the number of instructors with the divisions. Professor Monroe had dwelt on the point of having a sufficient number of instructors with the students. They made a point of having a competent instructor with every party of three or four students. In this way he thought the work in the field can be carried on with as great economy of time as work in the laboratory.

The matter of checking up the work is also important, and they found a great economy of time is brought about by having different parties do their work in such a way that the final result is a combination of the work of all the parties. He emphasized the fact that it is possible within the regular school year, without taking more than this one hundred and eighty hours, to give adequate instruction in surveying with the chain, compass, transit and level during the sophomore year.

When it comes to the higher branches of surveying, he thought it necessary that the work should be done outside of the regular school year. He did not think it is possible to give adequate instruction in topographical and geodetic work in regular term time when the student is engaged in other work. Here the students must have time for continuous field work where they are perfectly free from the strain of regular work. On this point of vacation work he would speak again. The only point he wished to make now was, that it is possible within the school year, when the work is properly arranged, to give a course of adequate instruction in such field work as is necessary for the young graduate to be familiar with in order to serve as a stepping stone to more responsible positions.

Professor Merriman wished merely to say that, after an experience of several years in Lehigh University, where very precise surveying work had been done by the senior class, he felt inclined to agree with Professor Jameson that such work could be materially abridged, and that they may have gone too far in that direction. Perhaps it would be better to spend more time on the elementary operations and less on the advanced work. For instance, in triangulation, his base lines had been measured with a probable error of one three hundred thousanth, instead of about one thirty thousanth, as mentioned by Professor Monroe. A largė amount of such precise work seemed unnecessary to fit a young man for the practice of surveying. But there were two points in Professor Monroe's remarks which he desired to notice. First, in regard to checking the work. That certain monuments should be established by which results can be checked, no one will deny, and it is particularly necessary for beginners, but he had no idea that the matter was ever carried so far as covering the ground with monuments and stakes of all kinds in order to check individual measurements. It seemed to him that this was so far removed from the conditions which prevail in actual practice that wrong ideas might be inculcated. The student should be trained to check his own work, and different parties should check the work of others, and thus methods of actual practice be taught. Lastly, in regard to the implication which had been made, and which he had heard there for the first time, that students are supposed to manufacture field notes in surveying for the purpose of passing in their work, it seemed to him astounding that any such idea should prevail. He was sure if there was anything calculated to destroy the character of a young man it is the implication from professors and instructors that he was going to do anything of this sort. It was contrary in every respect to the development of the high scientific spirit which should actuate every surveyor and engineer.

Professor Monroe replied that the object of the checking employed at Columbia was not so much to prevent dishonest work as it was to make sure that correct methods of handling instruments were adopted by the students. Unless they were able to check each measurement they could not possibly know whether the student had done his work accurately until the survey was completed, and even then the survey would often close by the balancing of errors. The main object was therefore to make sure that correct methods were used. In regard to the detection of fraud, he thought that the method adopted tended to remove temptation from the students, and he did not think that any honest student objected to having such temptation removed from him or from others. He knew practically in these seventeen years, that until they adopted this method there would always be one or two men in the class who would prefer to do their work in a dishonest way. There were several men expelled from the college for dishonest practices of this sort, and of course that had a very beneficial effect on those that were left, but there are always in every class one or two or three weak men who would act dishonestly by preference, and such men demoralize the whole class far more than any method of removing such temptations.

TRAINING OF STUDENTS IN TECHNICAL LITERARY WORK.

By MANSFIELD MERRIMAN,
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The courses of study in engineering schools generally occupy the close attention of students during the forty weeks of the academic year. It is indeed a common remark among students that they have little time for miscellaneous reading, much less for the perusal of technical books and periodicals. No definite course of training in technical literary work can therefore usually be attempted, yet in a certain way much can be done. Progress in this direction has been marked during the past twenty years so that to-day the graduates of our engineering schools are better informed regarding technical literature and better able to write technical articles than ever before.

The teacher can exercise a great influence in inciting the interest of students in technical literature by appropriate references during recitations and lectures. It has been the writer's experience that such references are received with the greatest interest when stated from a historical standpoint, namely, with the intent to illustrate the development of the science or art rather than to impart mere technical facts. For instance, in surveying reference can be made to its origin in Egypt, where it was synonomous with geometry, to the methods of the Romans, to the instruments used in the middle ages, to the early writers, to stern old Edmund Gunter, inventor of the scale and chain which now bears his name, to the American authors of a century ago, Jess and Rittenhouse, and to the charming essay of Amos Eaton, the first professor of civil engineering in our oldest technical school. When a student is interested in some of these, and when his knowledge of the subject is further advanced, he will listen with interest to references to articles regarding controverted points, methods of work or the judicial functions of surveyors. Many men in a class will consult the articles or books to which reference is made, and thus these topics often become matters of conversation among students during hours of leisure.

What has been said regarding surveying applies with greater force to geodesy, where the historical material is more abundant and more important. In all the subjects of a civil engineering course there is ample historical material to allow the same method to be followed. In strength of materials we go back to Gallileo and refer to his curious picture of a beam projecting from an ancient wall. In construction the great Egyptian pyramids with the ingenious speculations regarding their origin, and the substantial work of the Romans in stone and cement, inspire interest and admiration. In bridges, we go back to Cæsar and Trajan for but a moment, as the history of their marvellous development during the present century affords abundant opportunity for thousands of references. In sanitary engineering the ancient

Mosaic regulations claim notice, as well as the method pursued by Hercules in cleaning the stables of Augeus. In hydraulics, the numerous controversies regarding the laws of flowing water, which have existed among the earliest as well as among later writers, give especial material for interesting allusions.

Next in importance to the historical development is what may be called the personal element in engineering. A great structure is erected by means of the thought and labor of the designer. The story of the life of a famous engineer, of his struggles to overcome difficulties, of his success in accomplishing his work, together with a statement of his character and habits, always lends interest to a contemplation of the engineering problems connected with his name. So it is with books. If a student be told some fact or anecdote connected with its author, a certain degree of personal acquaintance is invoked whereby interest is inspired. "Not things, but men," is a motto which implies that human characteristics form, after all, the elements of greatest universal interest. Thus the instructor should try to bring before his classes not merely the names of great authors and engineers, but as far as possible the men themselves.

It is also the duty of the teacher to give frequent remarks concerning the current technical literature which appears in books, periodicals, and the transactions of engineering societies, particularly regarding those points which are exciting the greatest interest among engineers. There is scarcely a lecture or recitation whose subject-matter is not in one way or another illustrated or discussed in the columns of the technical press during a period of a year or two, and if the teacher be able to quote these or to read extracts from them, a live interest is excited whereby the daily exercises of the class room are made to directly connect with the real practice of the profession. Students should be encouraged to subscribe for and to read regularly an engineering journal, as well as to consult the columns of those which are taken in the library. The various indexes of literature should be pointed out to him and instructions be given in their use.

In the regular work of the class room something can be done to form habits of precision which will be valuable in technical literary work. For instance, in lecture notes, computations, reports on field work, estimates, and other papers which students are called upon to present, an orderly, neat, and systematic arrangement should be required. It has been the writer's custom for many years to require such papers to be written with ink, as he has found that when this is done the student feels a higher degree of responsibility and produces better work than when a pencil is used.

The graduating theses of students give especial opportunity for literary work. The subjects of these are generally selected during the first term of the senior year, and before undertaking actual designs or experiments each student should make a thorough search over the literature which relates to his special work. These researches often give rise to interesting and valuable discussions among students, and theses are sometimes produced which are most creditable to their authors.

But what is most beneficial in training students in technical literary work is yet to be mentioned. This is to encourage them to actually undertake the preparation of discussions and the writing of articles, not formally as an exercise of the class room, but of their own voluntary act in their own associations. Engineering clubs, institutes, or societies, formed by students and entirely under their own control, exercise a great influence in this direction. Papers prepared by students are read and discussed, debates are held, visits of inspection made, prizes are given for the best articles, while an annual banquet gives opportunity for the feast of reason and flow of soul. Such organizations are now formed in most of the technical schools of the United States and many of them publish annually or quarterly a journal containing articles prepared by its members. As an instance with which I am familiar there may be mentioned the Engineering Society of Lehigh University which was founded in 1873, and which, except two interruptions of about a year each, has been actively at work since. The number of members is about fifty, consisting of men in the junior and senior classes, by whom the society is officered and controlled. During the past eight years it has published a quarterly journal, each number of which generally contains from five to ten original articles, most of which are written by undergraduate students and a few by alumni and instructors. It is of course true that some of these articles are of little professional value, but it can safely be said that no student can prepare an article under the responsibility of publication without having received very great benefit. The only way to learn to write is to write, and the best training for a student in technical literary work is to prepare technical articles to be published over his own signature. Under this stimulus the student is urged on by the ambition of receiving commendation, and by the fear of unfavorable criticism, to put forth his best efforts and thus trains himself to produce good technical literary work.

METHODS OF STUDYING CURRENT TECHNICAL LITERATURE.

BY J. B. JOHNSON,

Professor of Civil Engineering, Washington University, St. Louis.

The current literature on all technical subjects is becoming as vast as it is valuable. It is quite beyond the powers of any one person to even scan it all in any one field, much less to read it. But the reading of all of it is probably as undesirable as it is impossible. The mind of an engineer should be a workshop and not a warehouse. If he knows where to go for a piece of information when he needs it, until it is needed it is better out of his mind than in it. The impossibility of reading all the valuable engineering literature, therefore, should not lead to its neglect. There is but one satisfactory solution to the problem. This vast store of professional wealth must be properly classified and made accessible. It is accumulating in all technical libraries, public and private, and it must be made accessible by proper indexing. No simple name or title index will serve the purpose, since in the course of a few years the number of articles under one name will be so great as to discourage investigation. The indexing must be done by technical experts, with discretion, taking only such matter as has permanent value, and giving such a short description of the scope and contents of each article as would enable any one to judge whether it is likely to contain to contain the particular information desired.

Such an index has been published by the *Association of Engineering Societies* for the past eight years. It appears monthly in the Journal of the Association, and at the end of each year all the notes of the year (some 2500) are brought together and rearranged into one annual summary. One seven-year summary of these annuals has now been published, under a single alphabetical arrangement, and bound in cloth. With such an aid it becomes possible to introduce the study of current technical literature into the schools. It is extremely important that our students should become somewhat acquainted with the most fertile sources of engineering literature while they are in college. Otherwise they may long remain in ignorance of some of the most important agencies and means of professional improvement. It is true they have little time at their disposal, and therefore they cannot afford to waste any of it in groping in the dark. They should be encouraged to purchase copies of the Current Index Summary, referred to above, or at least to use freely the copy which should be found in the school library.

The writer has found it an excellent method to have each student in the senior and fifth years to report on an assigned subject, before the entire class, occupying a half hour or an hour, the teacher taking his place with the rest of the class. Let him consult his index for sources of information, and let him have two or three weeks in which to prepare his talk. Give him free range of the library, where most of the matter indexed should be found, and let him bring into the class such books and periodicals as he wishes to use to illustrate his lecture. He should not read from these more than very short extracts, but use their illustrations.

In this way he may have learned something useful in the subject assigned, but if not he has at least handled and looked into all sorts of engineering journals, society proceedings, monographs, reports, public documents, and the like, which would not be listed in the library catalogue, and of the existence of which he would remain in ignorance but for this forced browsing, under the guidance of his topical index.

It is possible in this way to so interest our students in technical literature that they will acquire a thirst for it and when they graduate, and often before they get through the school, they will at once subscribe for one or more engineering journals and will want a number of good books about them; will join a local or national engineering society, and become studious and progressive men in their profession. This thirst for professional knowledge and the habit of acquiring it, or of acquiring the books and journals containing it, is a fair test of the efficiency of their school training. If they go from the school with a feeling of self-sufficiency, and a distaste for professional literature, they are doomed to narrowness and are sure to become time-servers, anxious only to hold their positions and to draw their salaries. The best possible means of cultivating in them the true professional spirit is to open up to them in an attractive way the vast and inviting fields of current technical literature which are now so accessible and so rich in profitable information.

DISCUSSION.

(On the Papers by Professors Merriman and Johnson.)

PROFESSOR LANDRETH commended the suggestion that the instructor should help the student to procure a library, and said that the teacher should keep that object in mind in choosing text-books for his classes.

PROFESSOR WOOD explained how the circumstances and conditions existing at different institutions affected the amount of reading students could or would do. He has his students take turns in examining current technical literature and making five minute reports before the class.

PROFESSOR SWAIN urged that the library should be of easy access to the students so that they may employ intervals between classes in the library. He recommended departmental libraries in preference to keeping all the books in one place.

PROFESSOR LANZA called attention to the opportunity offered by the students' engineering societies to give the prospective engineer literary training.

PROFESSOR TALBOT thought enough atttention was not given to cultivating the ability to write clear, simple English. He would go one step further than Professor Merriman: "The only way is first to write, and then have somebody criticise the writing." It may be necessary to have the paper re-written three or four times, but the result amply repays the effort.

Doctor Eddy called attention to the elaborate system of reviews and abstracts of technical literature now common in Germany, and hoped we might some day imitate them. Until then, we should be grateful for such work as Professor Johnson has referred to, which will come to be more valued as it is better known.

DRAWING FOR ENGINEERING STUDENTS.

By CHARLES S. DENISON,
Professor of Drawing, University of Michigan, Ann Arbor.

While not venturing the opinion that the subject of drawing, as we generally understand that ill-defined word, forms the most indispensable element in the education of the young engineer, it may safely be asserted that the large class of studies of which drawing forms an important part, and of which it is the means of expression, as well as the study and practice of the art itself, is and must continue to be, one of the fundamental constituents of the engineer's training. Indeed, no scheme of education intended to fit engineers for the best use of their powers can be considered otherwise than faulty and inadequate in which drawing does not occupy a conspicuous position. Admitting this to be the truth, it must also be granted that the allotment of time and energy to be devoted to the subject, and a suitable and logical arrangement and distribution of the student's work in drawing, with a view to the greatest economy as to time and the most hopeful prospect as to results, is a matter of sufficient importance to seriously engage the attention.

In order to get our bearings, a right definition of drawing is most desirable. It is a source of wonder how few works on the subject undertake to define it, and yet perhaps authors are wise in evading the attempt, as certainly a satisfactory definition is difficult to find. If, with Phillip Gilbert Hammerton, we say that "drawing is a motion which leaves significant marks," we find ourselves embarrassed by the comprehensiveness of a definition which confessedly includes writing and may easily include many things and acts entirely foreign to the generally accepted conception raised by the term. Let us consider as acceptable, if you please, the following definition from the "Century" dictionary, where drawing is defined to be, "The act of forming or tracing lines, as with a pen, pencil point, etc. Specifically, in the fine arts, the act or method of representing objects on a surface. Strictly, by means of lines, but by extension, by means of lines combined with shades or with shading, or with color, or even by means of shading or colors without lines; properly, a method of representation in which delineation of form predominates over considerations of color." In other words, drawing is either the act or the method of obtaining the projection of form upon a surface.

There appears to be a serious confusion as to just what should be embraced under the term drawing. If it is an act or a method of representation, should it, or should it not, include the mental processes which precede but lead to the act? Thus, for example, in many of our engineering schools to-day, descriptive geometry, which is a purely mathematical study, is included under this head, while drawing, strictly speaking, is employed in this study only as the means of representing the mental operations and illustrating the result in the solution of the problem in question. It would seem almost, if not quite, as logical to include algebra under the title of penmanship, as to regard the study of projections as a department of drawing, and yet, beyond a doubt, the treatment of this topic of "drawing for engineering students" would be conspicuously incomplete were it to omit the consideration of so important a department of the work. Not desiring to be at variance with what seems to be an established classification, we must therefore conceive drawing to be both an art and a science. An art as dealing with the manual practice of the delineation of form; a science in dealing with problems concerning abstract geometrical relation and position in space.

Evidently the skillful handling of the pencil, and the adroit manipulation of instruments is one thing; while the knowledge of mathematical form, the clear-cut conceptions of position and relation, that which, if you please, we may call intellectual insight into space, and which comes only from the careful study of the science of projections, is an entirely different thing. This also differs in turn from that concentration of attention, that power of visual memory, and the quick and accurate observation, which are such striking and valuable educational results of practice in the art. The writer's conception, then, of the most important ends to be kept in view, the vital objects to be attained by the courses and exercises in drawing for engineering students, are three in number.

First. The training and enlargement of what has been called the scientific imagination.

Second. The cultivation of the powers of observation and of visual memory.

Third. The attainment of skill in representation.

Attention will be called to these three objects somewhat in detail, and they will be taken in their inverse order.

Skillful representation, manual dexterity in the use of pencil or instruments is generally the inexperienced student's idea of success in the draughting room, considered by him as one of the passports to professional preferment, and the end and aim of his earlier efforts. This is all very well in so far as it goes, and should not be discouraged unless indulged at too great an expense of time and labor. But before very long the student discovers, perhaps in an uncertain way, that he is dealing with a form of language, a peculiar kind of thought representation, and that mere nicety of execution, delicacy of line and finish have precisely the same value here that they have in the written language, and no more. That it is an idea that he is representing and not a picture that he is making. In short, that it is an exact scientific record of facts with which he has to do, and not an artistic production only, after which he is striving.

Although mere beauty of finish is the least essential property of a technical drawing, there are certain closely allied qualities with which it will not do to dispense. While, beyond all doubt, the first and great requirement of a drawing is that it shall be correct and clearly legible, nevertheless, to be the work of an accomplished draughtsman it should present that sharpness and clearness of execution, a certain appearance of strength and precision which at once inspires one with the conviction that the maker is intelligent, alert, and worthy of confidence.

As a matter of fact, no technical drawing is above suspicion, or unclouded in its claim to credibility, which betrays by weakness of handling, any infirmity in training for his work on the part of the draughtsman, or even a lack of knowledge in so simple and yet essential a matter as the correct formation of letters and figures. Thus, while a reasonable devotion to the purely artistic appearance of the work in a professional drawing is to be commended, a student oftentimes, to whom has been given some slight measure of the artistic temperament, produces his work at too great an outlay of his capital in time and effort, on over-refinement of execution. At the same time no labor whatever should be spared in the achievement of clearness, accuracy and legibility. And this word "legibility" impels a word on the subject of lettering. To the successful draughtsman, considered simply as such, few parts of his training are more important, and few receive less attention. Merely from the lack of instruction, practice, and in most cases, an easily cultivated taste, a student after long and honest labor successfully accomplished, proceeds at once to shake our confidence in his mental capacity by disfiguring his work with lettering and with numerals of such wretched character that instead of adding an attractive and prepossessing feature to the drawing, reflecting the intelligence of a spirited workman, they actually jeopardize its true meaning and bring condemnation both to the drawing and to its author.

What has thus far been said relates largely to results obtained by training the hand: of the greatest practical value to the draughtsman, beyond a doubt, but by no means indispensable even to one who may become a distinguished engineer. The higher value of the study and practice of drawing—including in this term projections and graphics—is the education and expansion of certain faculties, without the possession of which, in vigorous activity and generous degree, the attainment of eminent success in any of the branches of the engineering profession is at least doubtful, while the one in whom these capabilities are trained to their full functional capacity will possess striking advantages over his uncultivated rival.

Among the faculties upon which the real study of the delineation of form exercises a strong and most happy influence, are to be mentioned attention, observation, memory, and what we may call the power of geometrical analysis, the ability, so to speak, of quickly reducing form to its lowest terms, or simplest relations. Free-hand drawing, that is drawing with the hand unaided by instruments, and guided only by the eye, must be regarded as one of the most satisfactory means for the cultivation of the above mentioned faculties. That the ability to make an accurate and rapid sketch of an object, a true and legible record of observed facts, is of value to the engineer, is too entirely obvious to call for assertion. But this "art of summary expression" is of even greater value, as a means for the clear and rapid expression of ideas which have no objective reality, than for the record of existing facts. Thus, while the Chief Engineer may possibly be able to delegate to his draughtsman the time-consuming process of drawing up his plans, he cannot dispense with the knowledge of, and the power to use, the very language of his profession. The ability to picture forth to others with a clearness and completeness that admits of no misunderstanding, the forms and combinations existing only in the brain of the master, is an absolute essential in the mental equipment of one who aspires to anything like leadership in the constructive professions.

This invaluable dexterity in the rapid bodying forth of his ideas by means of the free, rapid, but intelligent and economical use of lines and the suppression of needless detail, is to be obtained by the student only by the patient and earnest study of, and practice in, free-hand drawing. In this fascinating work he will find his powers of observation springing into surprising activity and his formal memory and appreciation of relational exactness strengthened to a degree alike gratifying and encouraging. Nor is this all. With proper instruction, he will learn instantly to recognize hidden relations of point to point, and line to line, the knowledge of which at once so simplifies his work and insures its correctness, as to produce in the student that tonic effect for which we strive and which we call enthusiasm. It is this training in the recognition of relation of position, the ready analysis of form into its chief geometrical constituents, which after all is perhaps the most valuable educational feature in the study of free-hand drawing. But the supreme function of this study for the engineering student is the cultivation, almost at times the creation of precision of conception. There is often a surprising grasp and clearness given to the imagination by a proper training in certain branches of the work. The power to create and hold a complete mental conception of a complex form, and then to operate upon it by intersections, rotations and developments, drawing conclusions and arriving finally at correct solutions, is one the value of which to the modern constructive mind can hardly be over estimated. I know of no exercise so admirably adapted to the expansion of this power of accurate mental picturing as the systematic study of that beautiful method of scientific representation invented by Monge and called descriptive geometry. The study of the orthogonal projection and of some of its more practical applications is of such superior efficiency in developing the constructive imagination, a result which it accomplishes as nothing else can, that the writer ventures to give it more than a passing word.

The analytical method of investigating the properties of form, while one of enormous power, fails by means of its complexity of symbolic representation to present to the mind a vivid concept of the form considered. The method by projections, while lacking the marvelous beauty of precision possessed by the former, is still exact within the limits of visual impressions, and sufficiently precise for most cases in practice, and at the same time does supply a most perfect graphical presentation of the body or surface under investigation. It is, then, this method by projections, which will give the student that feeling of familiarity with complex shapes, however situated, and which enables him to attack them with courage in any position, and to know what they really are, and how they look. As an illustration in point, when a student was once asked to make the projections of a hyperbolic paraboloid, the reply was a prompt offer to write its equation, coupled with a frank confession of inability to make the projections or to understand the surface. With a little careful graphical illustration the difficulties were cleared up, the projections understood, and then the law of generation of the surface really comprehended.

Thus the practice of precise, instrumental constructions by projection is a most powerful aid to the student in the attainment of that almost crystalline clearness of his mental view of mathematical form which alone makes it his. With imagination thus disciplined, he will have, comparatively speaking, little trouble with hyperboloidal wheels and helicoidal arches, and will in all his after work discover an immense gain in the direction of economy of thought and effort.

Viewed in this light, the study of what is called drawing assumes a very high order of both scientific and educational importance, while a knowledge of its practice, in some of its many forms, is essential to the professional success of not only the engineer, but of the scientific investigator of to-day, no matter to what department of research he may give his devotion. Trained and disciplined powers of observation, formal memory, and spatial imagination are of great value in all real pursuits, and that the earnest study of drawing by proper methods has a stimulating and enlarged influence upon these powers, the writer himself, after a somewhat extended experience in teaching, has no doubt whatever.

The detailed consideration of the practical question of the best allotment of the student's time to the various departments of the work would lead too far afield for the present purpose. The writer can only venture to express his conviction that in general the work of the first two years in the technical course should consist of something like one exercise daily in some branch of the study of drawing, after which he will be well equipped for the contest with his more strictly professional projects. The work of the first two years should include geometrical drawing, liberal instruction in free-hand work, and above all thorough discipline in descriptive geometry, and at least one of its practical applications. Also, somewhere within this period, should be found time for sufficient study and practice in the art of lettering to enable the student to at least avoid pronounced defects in this direction.

Geometrical and free-hand drawing are such indefinite terms that a word concerning them may not be out of place.

A course in geometrical drawing should consist largely, after the student has made the acquaintance of instruments and materials, of the most careful construction of real geometrical problems. He should be taught the various methods of construction by points of the most important curves, such as the conics, the spirals, and the cycloids, the actual construction of their tangents, normals, developments, etc., and not dissipate time even in the elegant execution of meaningless star-shaped figures and crystalline forms. And in order to do this it is not in the least necessary that the student at this stage in his instruction demonstrate the truth of the propositions employed, perfect familiarity with the methods being the aim sought. Later on in his analytical work he will welcome with happy surprise the simple demonstrations of his familiar early methods.

While the writer does not advise any attempt to make artists of engineers, still an engineer should command such a degree of graphical eloquence as may be obtained by a careful free-hand study of geometrical forms from well selected models, abiding faithfully and truly by the laws of perspective, and the observed shades and shadows. Passing from these forms, he should apply his rules and practice to the free, strong sketching of parts of machines and engineering structures. For civil engineers, some skill in landscape sketching is very desirable. Your patience will not be taxed by more than mentioning by name some advanced branches of work, the importance of which it is perhaps unnecessary to dwell upon.

For all courses in engineering, the scientific study of the scenographic and oblique projections. For civil engineers, spherical projections and topographical drawing and mapping; a course in stereotomy is essential to the civil engineer, and is advised for all courses. For mechanical and electrical engineers, an extended course in the graphical construction of gearing of all kinds and a thorough course in machine drawing. Some knowledge of photography is desirable and of "blue-printing" necessary, for all. After this the stupent may be considered equipped for his strictly senior work and left to employ his skill on his thesis drawings and professional sketches.

In the fierce modern rivalry for advancement to positions of usefulness and eminence, the young contestant with a successful future before him, must go into action with faculties alert and every necessary accomplishment well in hand,—a mind thoroughly schooled to precision of thought, with refined powers of perception, and an established habit of readiness, and of scrupulous exactness in execution. To these ends, the courses here very inadequately outlined directly tend. Further than this, the young engineer, striving for a foot-hold in his professional career, will often find his opportunity in being able to offer immediate and tangible proofs of a clear head and a skillful hand in the contents of his portfolio, which establish his claim to attention more promptly than his letters of recommendation. To the unknown genius lacking that magic power—influence—this visible demonstration of industry and ability may be, indeed often is, his passport into the arena, which once entered, will, with resolution and courage, prove a field of victory.

DISCUSSION.

THE CHAIRMAN presented the paper for discussion and called on Professor Ward Baldwin, of Cincinnati, to discuss it.

PROFESSOR BALDWIN had hoped that some one who had more experience in teaching drawing than he had would be called upon to discuss the paper first. A point made by the author, in fact all of the points made by him were of great interest. The speaker's experience had been more as a practical draughtsman. In teaching drawing in his own experience the most serious problem had been how to secure from the student accuracy, promptness, and neatness. He had tried several plans, and the one that had seemed to produce the best results had been to require each student to prepare a drawing and bring that to the lecture room, and to have an open discussion of the subject-matter of the drawing and the method in which it had been treated by the different students. The result of that method had been that the amount of work secured from the student had been materially increased. The stated time for presenting these drawings had led to more diligence on the part of those that were apt to be dilatory, and the result of the comparison of these drawings before the whole class had led to a certain amount of competition between the students to secure excellence. The result had been particularly noticeable in the work in graphical statics. The students were required to make their drawings and then scale the stresses from them, and tabulate them, and present their results in the class and make a comparison. After a few such comparisons, the first of which had developed a good many large discrepancies, the drawings had agreed remarkably well, showing that the students had made considerable progress in their skill in producing accurate results. One of the most interesting questions in his mind had been to decide what ground would be the most useful for the students in civil engineering to cover in their free-hand work, the purpose not being to cultivate so much their artistic skill as their ability to represent their ideas of structure clearly on paper. It had been an open question with him whether it were best to use models for this kind of instruction entirely, or even largely; whether it would not produce better results to use models but little, and rather lead the students to select their own models and employ the general principles which they had learned from lectures and sketching in the class, to produce drawings largely from memory of model constructions. That is the plan which he had followed with his students, and while he was well pleased with the results, he should like very much to hear on this subject from others.

Professor H. W. Spangler had hoped to hear this question approached from the side of drawing pure and simple, that is, exclusive of its application beyond the point which, in his mind, was covered by the title. That is, he understood that the teaching of drawing had nothing to do with graphical statics. He did not see that the teaching of arithmetic had anything to do with the mechanics of materials. He looked at drawing from a very narrow standpoint, perhaps too narrow, but what he was most interested in was the question of free-hand drawing. That, to his mind, was a decidedly serious question, as he had not been able to satisfy himself, and had no assistants who were able to satisfy him that the conditions of affairs which exist under his control are the best. That it is a serious one, those who have charge of this work realize when it is stated that to-day the free-hand drawing taught to mechanical students is limited strictly to the free-hand drawing necessary to make working sketches that are afterwards to be worked up. He did not believe this was right. He was satisfied that it should be much broader than this, but just where to draw the line he did not know, and he should like to have somebody who has had experience enough in this free-hand drawing, that is, somebody who is engineer enough to use his free-hand drawing outside of the college work, to solve this problem. That is, he did not want to teach free-hand drawing because it is a good thing to do, but because it is a good thing for an engineer to know. He would like to know just how far it is practical to carry free-hand drawing instruction. It is well known that when one talks with men who are not engineers he must do a certain amount of free-hand drawing. Now, business men as a class are sharp, and a picture conveys a pretty clear idea. Is it desirable that we should go beyond this with our students? One goes into his laboratory and selects a machine and the students sketch it, and the sketches are worked up afterwards. It is a very narrow course, but he did not see his way out of it; that is, he did not believe it was worth the time to give an extended course in free-hand drawing, and he does not know how to give a small course. There are times when a man must do free-hand sketching, but he was satisfied that a man who can make working drawings can make free-hand sketches. He would like to hear from somebody who has been through this mill, as to just how much free-hand drawing is of value to engineering students, exclusive of the work that is necessary to give an understanding of the mechanical drawings.

Mr. Frank M. Dunlap, M. Am. Soc. M. E., asked if an outsider might be permitted to say a word from the standpoint of the practicing engineer? He remembered his experience in college in the matter of free-hand drawing. He was taught drawing very largely from colored plates, and he was induced to shade his work up from those plates with the pencil, roughly to be sure, but to an extent which he at that time thought to be unnecessary. He had had some little experience in the shop before entering the college. He found now that when he goes to talk, as the gentleman had said, to a person who is not an engineer, he found that his pencil talked faster than his tongue did. He never shaded up anything in making sketches; he confined himself largely to outline diagrams and he thought that the gentleman's process with his students a very good one. He thought that what idea of shading and shadows they get from their ordinary course in drawing will give them enough of the matter of form to enable them to put in what little they need beyond, and a more extended course in what might be called projection sketching from the sketching of two or three projections of a piece for the sake of working them up into working drawings, would be the most valuable that they could have. He wanted to say one word with reference to what Prof. Denison said in regard to an educated imagination, the ability in examining a drawing to see the article stand right up in front of one. He remembered a classmate of his who took his descriptive geometry by actually memorizing where each line on the plate went, and if anybody gave him different conditions he was unable to put his problem on the black-board. While he has since made a good theoretical engineer, a good engineer in a mathematical sense of the word, the speaker did not believe he would ever become skilled in construction.

PROFESSOR SPANGLER remarked that the author of the paper, in speaking of the drawing necessary to a mechanical engineer, said something to the effect that graphical delineation of gearing was something that would take up too large a per centage of the time. He wished to strongly endorse that opinion. He believed that the time spent in the accurate delineation of gearing is time thrown away. It did not seem to him that an engineering school is the place to develop immense charts of gearing. While there is no question that in particular circumstances this class of work has resulted in great value to the engineering profession as a whole, still from the students' standpoint he could not imagine what educational value the actual drawing of gearings could have.

VACATION WORK.

By ALFRED E. BURTON,

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Practical surveying enters as an essential feature into every course of civil engineering study. Its position in the curriculum is assured. There is little need to plead for its wider recognition. A certain amount of skill in the use of surveying instruments must be guaranteed to the young man who is to use these tools at the very outset of his career and for whom they often furnish the only possible means of beginning professional work, but in the practical application of the principles of surveying much time can be easily wasted, and it is important to see that surveying does not crowd from the course of study subjects of a more advanced character and of a greater ultimate usefulness to the civil engineer. It is with the idea of suggesting a suitable method for condensing practical instruction in surveying that this plan for vacation work is presented.

Practical instruction in surveying is naturally divided into two parts. First, that which is generally considered to furnish sufficient training for the land surveyor, and for the town or city engineer. Second, that which is the special training for the topographer and geodesist. The first part can, without embarassment to other studies, be readily incorporated into the term work of the four-years' course. The second part requires so much time for its proper development that it cannot properly be included in the term work of the regular curriculum of civil engineering study. The following suggestions with reference to the condensation of the first kind of surveying practice are derived from some ten years' experience in teaching. They are:

First, that whatever time per week is given to this subject should be so arranged as to permit of continuous hours of work, thus producing in the field and drawing exercises a condition of things analagous to that of actual practice and reducing to a minimum the loss of time incident to the beginning and ending of such exercises.

Second, the employment of a large corps of instructors, so large in fact that it shall be possible in field exercises to have one instructor for every three or four students. (This last condition can be attained without great expense by so arranging the scheme of recitations as to permit all the instructors regularly engaged in other branches of civil engineering to give their time for a few hours to this special work.) In this way the maximum amount of instruction can be given in the minimum amount of time.

According to the tables recently published by the *Engineering News* the Massachusetts Institute of Technology appears to give very nearly the minimum amount of time to surveying when compared with other technical schools, yet the writer believes that the student is given there as much practical instruction as is needful. Six hours a week for thirty weeks is given to instruction in plane surveying and levelling. Two hours a week for thirty weeks is given to instruction in the use of instruments employed in topographical surveying. Practice in the field operations of geodetic and topograghical surveying is given during the vacation and for the greater number of civil engineering students this work is made optional. It is only when we wish to meet the demand of our general government and state surveys for skilled topographers and observers that this brief course in surveying appears inadequate. This demand is not a great one and the number of students who desire to follow this work and are naturally qualified to do so is small. Why then force every civil engineering student to specialize further in this line? Why exclude those especially fitted and desirous of taking this work from an opportunity of obtaining proper and adequate training?

The writer does not think the term periods of a regular four years' course allow time for the proper training of a topographer or observer, in connection with the other studies of a civil engineering course. His suggestion for meeting this difficulty is to establish a course of field work, or a school of application, during one or more of the summer vacations. Require students who desire to become topographers and observers to attend to this course, and to specialize their studies subsequent to this work by omitting some subjects which may be really essential to the general civil engineer but not to them, should they follow their chosen professional career. Thus there can be graduated better civil engineers and better topographers and observers. This change need not be very radical and should only be introduced in the closing years of college work, but it seems to be essential, and in order to better develop such a plan the writer has thought it best to describe the method of carrying on the summer school of the civil engineering department of the Massachusetts Institute of Technology during the past five years. The essential characteristics of this school are:

First, it is an entirely optional part of the general civil engineering course, it being required only of students who wish to take the more extended course of geodesy in the senior year in place of some of the work in bridge design and railroading.

Second, only students in the junior or third year class of the civil engineering department in good standing or students from other departments or colleges who can show themselves equally well prepared, are allowed to attend.

Third, the time is limited to four weeks in the month of June.

Fourth, the subjects considered in the summer school are field problems in geodetic, topographical, hydraulic, and geological surveying.

Fifth, the location of the school is determined entirely by the adaptability of the region for the illustration of the problems considered.

Sixth, the number of the teachers is so proportioned that there shall be at least one teacher for every four or five students.

Seventh. Very little or no instruction is given by lectures or by text-books, and no recitations are required. It is essentially a school for the application of principles already acquired. Lectures are given in order to sum up the results of the field work and to keep the work of the whole school before the mind of each student.

Eighth. All work of the students is so arranged as to be susceptible of being tested for accuracy by the students themselves, and the method found most suitable to be employed for this testing has been to so arrange the work that different parties of students may check each other, or the student checks himself by employing different methods for obtaining the same result. So far as possible, wherever the plotting is a check of the work, it is arranged that the plotting shall be done by other students than those who obtained the notes. These checks correspond with those existing in practice and seem to have furnished satisfactory tests.

Ninth. One of the most important features of this school is that all the work is made subservient to the one object of giving equal and adequate instruction to all members. No attempt is made to accomplish any definite amount of work beyond the direct usefulness of that work as a means for conveying practical knowledge to the mind and hand of the student. The question of economy of time is insisted upon from the beginning, but the sacrifice of uniform instruction for the completion of any certain area of work is absolutely avoided. The work, when finished, may be valuable and may be incorporated into other work of commercial value, but the desire to make the work for a specified purpose is studiously avoided. The fact that a student develops unusual facility in certain directions rather shortens than lengthens the portion of time for which he may be assigned to that particular task.

The work of the summer school of the Massachusetts Institute of Technology has been carried on during the last five years at several different localities. These changes have been made partly on account of the difficulty of finding an ideal location and partly because there are certain problems which are best illustrated by making a fresh reconnoissance the first step in the work. The school of 1888 was held at South Deerfield, Massachusetts; that of 1889 at Schoharie, New York; that of 1890 at South Deerfield again; that of 1891 and 1892 at Delaware Water Gap, Pennsylvania; that of the present year in the Adirondack region of New York, near Keeseville.

The attendance at these summer schools has never been large, as the requirements for admission have been adhered to strictly. The average number of students attending has been fifteen. This year there were twenty-five students.

The speaker then described the vacation work of the Massachusetts Institute Technology orally as follows:

He first described the hydraulic measurements. He had selected as an illustration their work of the year 1892, at Delaware Water Gap, Pennsylvania. He showed wall diagrams illustrating the work. The discharge of a stream and of its two branches had been measured by two methods, floats and meters, and these were made to check each other. The local conditions at the several sites were also very different. In this way the student's work can be checked without any suggestion of attempted fraud on his part. The students took great interest in doing all their work with the greatest care.

The speaker then described the experimental geodetic work of the class. This consisted in the measurement of the base line and the horizontal and vertical angles in a small system of triangulation. This was a new country, visited by the students for the first time, and the problem of reconnoissance for points was an important one. It was a region particularly well situated for developing this portion of the work. In the first place, it was a valley surrounded with hills. The reconnoissance readily developed the fact that a large quadrilateral of very good shape could be obtained without much difficulty. The construction of a signal took about one hour and a half of the students' time and was a profitable lesson. The location of the base line was not ideal, but not very far from it. It was an important fact that the government coast survey had worked up into this region, and had established here one of their points. From the Coast Survey we obtained the latitude, longitude, and elevation of this point. The work, therefore, could all be referred for its geographical position and for its elevation to this point if it could be connected with this system of triangulation. That was done, and the latitude and longitude determined, so that the geographical positions of all these points could be worked out and the L. M. Z.'s determined.

The system pursued in this work had been strictly that of the coast survey observations. He referred to the measurement of the base line as part of the geodetic work, and he did this not to show what amount of work was done, but rather to show what this field instruction might do in developing in the mind of the student a spirit of investigation. They had measured a base line each year of the five years of summer school work, with the steel tape. It is well known that measurements with the steel tape may be made with an accuracy of one in one million. So that with this simple apparatus they might be considered as doing something of a geodetic character. They had developed an apparatus for doing this work from year to year. The students had been sufficiently interested so that when suggestions were made to them in regard to the development of the work they had responded in such a way that he felt that they had developed an apparatus which for easy manipulation in the field, and for accuracy of results, compared very favorably with any that he had ever seen. The tape was suspended above the ground. To find the length of the tape it is placed in the same position in which it is used in the field, over a space of known length. All that could be done in the summer school was simply to repeat measurements and see whether they agreed. The problem was to suspend the tape in line so that there would be as little friction as possible at the points of support, to stretch the tape with a uniform pull, and to determine the temperature of the tape. The last of these was the most difficult, and he could not say they had solved it. He would say in regard to the intermediate supports, it took a good deal of time to drive stakes and put in nails, and he did not see any necessity for it. They had a light line of poles which could easily be aligned accurately enough by the eye. Then on these posts they put hangers, which could be raised, and on these were placed hooks for supporting the tape. These formed the points of suspension, which were very quickly aligned by the eye, and were as firm as need be. The speaker here exhibited a stretching devise which he said had been devised by H. C. Bradley of the class of 1891. Speaking of the results obtained he said they had measured two lines by repetition, a mile in length, the variation between these measurements being only one part in one million. They had measured a line of a kilometer in length four times with a probable error of the mean of one part in one million five hundred thousand. The temperature question is a thing which has been difficult to contend with. They could only get the results referred to when, by using the thermometers, they can call the temperature of the air the temperature of the tape, and that can only be when there is a drizzling rain, or when the measurement is taken on a very cloudy day, or perhaps possibly at night, as Mr. R. S. Woodward of the coast survey had suggested. In the results referred to the best conditions had of course prevailed.

The speaker referred to the base line work the past summer. One of their students was so deeply interested in this work that after taking a post graduate course at the Harvard University, he wished to come back to the summer school and try some experiments with the galvanometer for the purpose of finding the temperature of the tape by the variation of resistance. The results were hopeful. Some tables were shown which indicated that it could be done. Experiments which had been made since the summer school closed were still more encouraging, and he was in hopes that something might come of it.

In regard to the rapidity of the work, he found there was no difficulty whatever in taking a measurement of one hundred meters in fifteen minutes' time. This included the alignment of the points of support, the putting in of the stakes at either end, the leveling of the points of support and taking and recording the results of the measurement. This could be shortened by experienced observers, and the speaker believed these methods of measurement, involving an accuracy of one in five hundred thousand, could be used for the measurement of lines in the preliminary laying out of city lots. At least these methods had stimulated the students to original work in perfecting so simple a method of measuring to such extreme accuracy.

The speaker next referred to the topographical work proper. This is the work that he thoroughly believed needed continuous field practice in order to give adequate instruction. The best instrument for topographical work had seemed to him to be the plane-table. There was a great difference of opinion on that point among civil engineers, but there was no difference of opinion on some of the government surveys as to how the work should be done. When they want topographers, they want men who can use the plane-table, so that if students are fitted for topographers and geodesists, they must use the plane-table. He believed it to be impossible to give adequate instruction with the plane-table without using some particularly well adapted locality and carrying on the work day after day with the student. They do not spend more than a week's time on this subject with any one student, but a week of continuous work, it seemed to him, was necessary in order to give this proper instruction.

The speaker explained how a plane-table triangulation was first made, working from the measured base line, and the position and elevations of the triangulative stations fixed on the map. The elevations were obtained in such a way that they were not accepted until three different determinations check them. The great advantage of plane-table work was that a mistake could not be made. The student could not make a mistake and deceive his instructor. If a mistake has been made he cannot adjust the points and the work must be gone over the next day. After getting his framework, he determines the elevation of the table by sighting on three known points, and then he goes ahead. The ground is thoroughly covered, and a correct map is obtained. He felt certain of this because every time the table was put in position there was an opportunity to test every other point. By means of this instrument alone every man had to make a map of the area. So much for the matter of plane-table work in the summer school.

Stadia work is taught also in connection with this, but as he could not test that work until it was plotted, they had to wait until the school had closed to get that time.

He spoke also of a portion of the work which consisted in the location of contours underneath the water A tracing on the wall showed this work. It showed the lines of soundings taken and the different systems used in locating the boat, and the practical work of the sextant in locating these points.

This covered the principal features of this summer school work. There were, however, other points that were taken up. The barometic work was very useful. Several aneroids were taken along with the party so that the students become familiar with them, and there is no need of cautioning them on the results obtained by the aneroid after they have used four. Photographic work in connection with surveying was also an incident in the summer school work. The use of the range-finder for measuring long distances was also taught. This was borrowed from the artillery service, and four forms of range finder were used so as to see which would give the best results.

This work was confined to four weeks. Each student had about an equal amount of time for each class of work, the work was prosecuted throughout the whole of each day and the students were changed from one class of work to another, but by means of lectures in the evening the work of the whole school was brought before the stüdents, and it was surprising to see how stimulating it was to see the results as reported from the plane tabling and soundings. The speaker advocated the use of the plane table in the summer school, even if it was not the most useful instrument, simply to keep up the interest of the students.

The keeping of accurate field notes was, of course, insisted on, and he thought the only thing that he could add in regard to the plea of vacation work was that it came at a time when the student has just finished his heaviest mental labor; when his mind is most active and his body has had the least amount of exercise. Here was a chance for a perfect rest without idleness, and he had found that their students never complained of being tired of this work when it was arranged in this way.

DISCUSSION.

Professor J. B. Johnson said he had been very much interested in the description of this work, and he doubted if anyone could improve on the methods that had been presented. He believed it was coming to be a common practice to take a portion of the summer vacation for this survey practice work. He felt that there must be a period of field work that is continuous, away from the school and from the homes of the students, where they can put in a period of three or four weeks continuously, and in a business way. He considered it was absolutely necessary also to the proper finishing up of the study of surveying for civil engineering students. For the other engineering courses such a knowledge of instruments as could be obtained during term time was sufficient. He did not want to make any extended remarks, except in a commendatory way, of everything that had been said, but where there are several ways of doing a thing, all may be equally good, when equally well carried out. It was hardly fair, however, to compare one method which is executed with the greatest care and perfection, with another method which perhaps is performed very poorly. So, in regard to comparing transit and stadia work with that of the plane-table, he thought that the stadia and the transit had not been dealt with fairly. The gentleman had said he could not tell anything about the results of the stadia work until after he returned from the field at the end of the season's work. The speaker thought if it was to be done in that way it should not be done at all. He always knew before he retired at night whether the work of the day checked or not. The day's work, so far as the instrument stations are concerned, should be worked up, elevations checked, and the traverse line platted that night, so that the party who goes out and takes up the work the next day knows whether he should go on with the work or revise it. He thought, therefore, the gentleman had given the transit and stadia hardly a fair showing, and that the two methods could not be compared on any such basis as that described. He had found this to be true—

and it had been his business to try and find out what were the facts in the case—he found that those who had been educated to the use of the plane table think that is the only way to do it. He believed he had never found an exception to that rule. On the other hand, those who have been educated and have had long use with the stadia and transit, think that is the only proper way. He had never seen an exception to that rule. Now, there have been some who have been trained in both methods who give them about an equal showing. The speaker inferred that the author had been educated on the coast survey, and he had never seen a man who was educated on the coast survey who would admit that there were any other methods than those of the coast survey. However, the coast survey was now adopting the steel tape, which had long been used by other government departments, and it had been forced upon the coast survey by a man who had long been connected with the United States Lake Survey. It was tried with a great deal of reluctance; there was in fact a great deal of sneezing at the steel tape by the coast survey assistants. He knew something about Mr. Woodward's troubles there in this matter. The speaker thought there was not only very great ability on the coast survey, but that there was a great amount of prejudice against anything that originates outside of that service.

He fully believed in the efficiency of the plane-table, but what is the situation in the west? In the east men are fitted perhaps for government surveys. In the west it is rare that a young graduate finds employment on these government surveys, except it be work on rivers and harbors where the plane-table is practically never used at all, and where the transit and stadia are used altogether. Probably all were doing the right thing. The speaker taught the plane-table method somewhat, but the time is too short to teach both methods thoroughly. He did not seek to fit men for the government service especially, but for such work as comes along in a civil engineer's practice, and possibly in city engineering. The man engaged in city engineering has some little topographical work to do, there are some new conditions to meet, some sewers to be put in, etc. He has his transit, and all he has to get is a couple of stadia rods. That instrument is always at hand, and it is much easier for civil engineers to provide themselves with these stadia rods than with plane-tables which are not useful in any way except for topographical work.

The speaker said in closing that he thought he had never seen field work so well presented, and apparently so well done as it was evidently being done by the Massachusetts Institute of Technology. He was very much gratified by it.

Professor Humphreys said he was thinking when the author of the paper was describing the work of the student who devised the apparatus for stretching the tape, that possibly the young man had read Professor Johnson's book, in which the same problem was solved in very much the same way. In regard to driving stakes and nails, of course there was a good deal of labor in preparing the line beforehand, but in about three quarters of an hour on the occasion of the very first measurement of a base line that was ever made by this method, they measured two miles. The advantage of having the line prepared in advance so as to use the minimum amount of time in measuring it, being that they can take advantage of the most favorable conditions. As the author said, the most difficult problem was to determine the temperature of the tape. If that cannot be done, the temperature of the thermometer can be found, and a time must be chosen when these will be as nearly identical as possible. At night fair results can usually be obtained. Of course a drizzling rain offers the best conditions.

He agreed with what Professor Johnson had said in regard to the jealousy between the engineers of the coast survey and others. He believed the steel tape was forced upon the coast survey because they could not do without its use without making themselves ridiculous. The stadia method had been used exclusively on the Great Lakes, and he thought they will have it on the coast survey before very long, but he did not think they would give up the plane-table. With an accurate transit vertical angles can be read with a great deal more accuracy than with a plane-table.

Professor Merriman remarked that, judging from his own experience, nineteen out of every twenty engineer graduates, during the first ten years of their practice, never see a plane-table. They are connected with all kinds of miscellaneous work, and, therefore, it was his opinion that the method with the transit and stadia in topographical work was far more advantageous.

In regard to the use of the plane-table on the coast survey, it seemed to him that if the coast survey, instead of having used it so much, had used the transit to supplement it, it would have covered a great deal more ground at less expense, and the control of the interior space of the whole country would not have been transferred to another department at great expense.

As to the methods of instruction, he believed in everything that had been said except one, namely, that the instructor should be in charge of a party of two or three. It seemed to him, in that case, the instructor would do most of the work. As soon as the men begin to do work that is not quite right the instructor sees it and puts it right. It is a great deal better sometimes for the student to go on for awhile and make errors and afterwards discover them, than it is for the instructor to follow him so closely. It seemed to him that in measuring the angles at one of those stations, if one man were sent out alone without an instructor, the drill received would be a great deal better in many respects, and that the field work should be divided up so that the students themselves would form heads of departments, each one under the direction of its chief, trying to do its best work.

He could only say he had been very highly gratified at the presentation that had been given of the work that had been done, and especially desired to congratulate the author on the excellent manner in which he had presented it.

Professor Ricketts thought the section was deeply indebted to Professor Burton for his very valuable and interesting account, and he had nothing to add to the technical discussion, but he would like to add his testimony to the value of vacation work. By throwing the surveying into the summer vacation the schools were able to get more time for other subjects during the academic year.

At Troy they require every member of the sophomore and junior classes to take a summer course in surveying, generally in the Adirondack region, for one month, from June 1st to July 1st. They work six days in the week and ten hours a day in the field for a month, and at night make their maps and work up the notes. The work is made as practical as possible. Of course, in the mean time during the first two years, the students learn the use of the ordinary surveying instruments so that when they go to the field they are fully prepared to use them. They also require a thesis written by every member of each class during the summer vacation, and it seemed to him that that was quite a valuable addition.

Professor Talbott was glad to learn that the gentlemen were teaching their students to make their own checks in the carrying out of their work, and there was another point in that connection that had not been mentioned. The first time that a young graduate goes out to do work for himself, if he has not been properly taught in this respect, he will either find that he is entirely careless as to whether his results are correct or not, or else he will be full of a great sense of responsibility as to whether his work has been carried on correctly without knowing how to himself solve the difficulty.

There is a value, too, in this method of field work, in that it gives to the student a discipline, both in charge of a party as chief in the way that has been recommended and also as a subordinate.

Professor Burton, in closing the discussion, said there was only one point he wished to refer to, and that was the impression he must have given in regard to the number of instructors. He said that they had a number of instructors, and that they would have one instructor to every four students, but they sometimes sent out parties without instructors. He did believe thoroughly in putting the responsibility on the students, but he wished to save the student's time and give him the greatest amount of training in the limited time at their disposal.

He also wanted to say, in regard to the plane-table as a method of instruction, that it should not be incorporated in the regular term practice of the student. Its place was in the vacation course. There were not enough topographers demanded, however, to make it worth while to use the plane-table with all students.

GRADUATING THESES.

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In order to obtain a degree in most, if not in all, of our engineering schools, the candidate is required:

First. To pursue certain lines of study, and of laboratory work.

Second. To pass certain examinations.

Third. To prepare and present a satisfactory thesis.

In regard to the first, it is evident that the object in view is to give the student instruction, and thus to prepare him to engage successfully in the work of his chosen profession; and whenever the question arises whether certain studies or certain laboratory work should be introduced into the course, and to what extent, there is one and but one criterion by which to determine the answer and that is, whether the result will be to impart to the student such instruction as he most needs to lead to his success in life, after he takes up the practice of his profession.

It is plain that the course should be so arranged as to attain the above stated object as effectually as possible.

When, on the other hand, we consider the second matter, viz.: examinations, we find that their object is to form a partial test of the students' progress, and to keep him up to his work. They have nothing to do, except incidentally, with imparting instruction, and are merely a necessary evil with which we, of this age, have not been able to devise a suitable means of dispensing, but which we hope may be dispensed with by some future generation wiser than our own; for, if the student could be kept up to his work without examinations, and if some perfectly fair means of rating his progress could be devised, then the time gained by omitting examinations would be much better spent in extending and in improving the course of instruction.

When we take up the requirement that the candidate for the degree is to prepare and present a satisfactory thesis, we must first consider why this requirement should be made at all. If the only, or the principal object to be accomplished by the thesis were to serve as a test by which to determine the fitness of the candidate for graduation, then the thesis would become not a necessary but an unnecessary evil, and the time consumed in preparing it would much better be spent in further study. The requirement of a graduating thesis, therefore, on any such ground as this, would be entirely indefensible.

But the writer does believe thoroughly in the requirement of a thesis, as a most important feature in the course of instruction, not merely in the case of a candidate for graduation, but also, in the case of a special student who is far enough advanced in his professional work to undertake one. In determining what should be its nature, however, we should refuse to consider any possible functions that it may fulfill, as a method of ascertaining the amount of progress the student has made, or his capability, but the question should be decided solely with reference to the part it would play in imparting instruction of the kind necessary to prepare the student to make a success in his professional life in the long run. That the principles enunciated above have been, and are frequently disregarded, will be evident to any one who will examine the practice of engineering schools in the past, and that followed in many cases to-day.

Probably, in the early days of engineering schools, the requirement was made because it had been customary in some of the colleges to require of the candidate for the A. B. degree a so-called thesis, or composition, no very distinct idea having been formulated as to what should be the object of a thesis in an engineering school.

The thesis required for the A. B. degree by some of the colleges has, in many cases, been merely a composition to show that the student can write English intelligibly; and at their best, these college theses have had for their object: first, to show that the training of the candidate is such that he can take up and discuss some subject; and second, that he can express his ideas clearly, and in well chosen language.

As to the subject itself, it is likely to be one of a general character, as a political or literary subject, and often one about which there may easily be a variety of opinions. These ideas transferred to an engineering school would give rise to a class of theses, of which there have been many, in which the student describes some existing or proposed engineering work, and discusses its features to such an extent as to show that he is able to understand it, sometimes making the calculations for some or all of the stresses by means of formulæ in common use, and also making a certain number of drawings.

Such work as this may, of course, benefit the student to a small extent, but the part that it can play in his instruction is very small when compared with what ought to be accomplished by a thesis.

On the other hand, projects or designs are often made which are so extensive that they would require the careful thought, study, and work of an experienced engineer. In these cases the student does not undertake to study and design the details, but confines himself to glittering generalities, since the very extent of the problem precludes the proper consideration of the details in the time at his disposal.

Hence, since the details have a controlling influence, it is more than likely that such a design as I have described above would be entirely unsuitable to be carried out in practice. Designs, whether used for theses or not, should be of such a character that the student may be able to work out all the details.

Theses, of the kinds I have described above, and others of a similar nature, have for their main object to show what the candidate can do, and not to increase his powers of doing good and thorough work. Nevertheless, there have been and are still too many theses written and accepted, of the kinds described above. Indeed, this character of thesis is very likely (though not necessarily) to prevail in schools where there are no laboratories, or where laboratory work has not been introduced to any great extent.

Let us turn our attention for a few moments to a consideration of the fact that the development that has taken place in our engineering schools during the last twenty years has been phenomenal. Whereas a variety of influences have contributed to bring this about, all tending to put the schools more and more in touch with the industrial work of the world; nevertheless, one of the most powerful and effective agencies has been the introduction of laboratory work, and especially of engineering laboratory work, into the courses. It has been the practice of the schools, for a great many years, to require students who are fitting themselves to become chemists, to perform chemical laboratory work with their own hands. The developments of later years have also proved beyond question that both laboratory practice and field work are essential to any proper study of the various branches of the natural sciences, and both are now very generally required of students of these subjects. Physical laboratory practice, performed by the students themselves, was first introduced about twenty-five years ago.* To perform experimental work with accuracy and thoroughness, to observe, note and collate the facts as they occur, to make measurements with the proper degree of precision, and to understand and to be able to determine the limits within which the conclusions can be assumed to be correct, has proved to be one of the most efficient means of training the student. But now there has arisen, in addition to the above, another most important development in the line of teaching students of engineering to perform the work with their own hands, to observe, to experiment, and to investigate, and that consists in the establishment of engineering laboratories in the various schools. Thus we find a variety of these laboratories: as laboratories for testing the strength of materials, steam laboratories, hydraulic laboratories, electrical engineering laboratories, mining engineering laboratories, chemical engineering laboratories, etc.

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*We know of a school in this country where it was done thirty-five years ago.—Eds.

Engineering laboratories as a factor in the course of instruction were proposed by Professor William B. Rogers, about 1861, and a steam engineering laboratory was established at the Massachusetts Institute of Technology in 1874, and placed under the direction of Professor Channing Whitaker: this one, so far as the writer is aware, being the first laboratory of the kind ever established. Then, one year later, Prof. A. B. W. Kennedy made an address in which he advocated the establishment of such a laboratory at University College, London, but did not succeed in establishing it until 1878. The idea has been very slow to permeate the English and the European schools, but our American schools have been rapidly adopting it.

These laboratories have exerted a far greater influence than any other agency upon our engineering courses; by bringing them in touch with the live problems of the day, and by furnishing to the theoretical portion of the instruction an ever wider basis of experimentally ascertained facts upon which to build. The direct objects to be accomplished by these laboratories are: first, to give the students practice in such experimental work as engineers, in the pursuit of their profession, are called upon to perform; second, to afford some experience in carrying on original investigations in engineering subjects, with such care and accuracy as to render the results of real value to the engineering community; third, another important function of such laboratories, which is entirely consistent with the other two, is that of taking up and carrying out systematic investigations of engineering problems. This can be done in a laboratory, whereas it is only with great difficulty that it can be done in a shop, or in a manufacturing establishment.

By publishing these results from time to time, the laboratories will serve to add gradually to the common stock of knowledge.

Of course, as a rule, it would not be suitable to expect the student to originate and carry out research without aid from his teachers, but when the necessary aid is given, and the necessary supervision exercised, a considerable amount of research can be accomplished in these laboratories.

First. The regular laboratory experiments can be so arranged by the instructor that they shall form an element in an investigation, the students taking the observations, and working up the results, the necessary amount of checking being done, and the necessary supervision being exercised to insure correct results.

Second. Original researches can be carried on in the laboratory in connection with the graduating theses. In this case it is necessary for the teacher to exercise the requisite supervision, and to furnish all the aid needed, but the student is made to look upon the problem as his own, and is taught how to carry on original investigations.

While the laboratory is the most fruitful source of original research, and has served to render it easier to require that the theses shall be of this character, and hence while most of the theses which involve investigation involve also laboratory work, nevertheless it is true that there are other lines of research possible; but the laboratories have given a greater impetus than anything else to this class of work.

CHARACTER OF GRADUATING THESES.

Having thus noted the special facilities afforded by the laboratories for theses involving original research, let us turn to a consideration of the proper characteristics of a graduating thesis. We began by laying down the principle that it should be planned solely upon the basis of the purposes it will serve in the instruction of the student. Arguing from this as our standpoint, it would seem that much the most suitable characteristic of a thesis is that *it involve an element of research.* A thesis, where this is the case, teaches the student in a much more effective manner how to carry on investigation than can be done in any other portion of the course of instruction, whether lecture room or laboratory work. All teachers of engineering are aware that it is very difficult to make a student feel that responsibility and self-reliance in his work which a practicing engineer must feel. The more the student can be taught to feel this responsibility, the more he can be made to take hold of any piece of work as though it depended upon him to find out how to do it (provided the teacher exercises such a degree of supervision that the work is properly done), and the greater will be his success in the work of the school, and the better will he be prepared to meet the problems of life. The gratuating thesis affords a far better opportunity than anything else to accomplish this result, if it is properly chosen and managed, and the one that accomplishes this the most efficiently, is one that involves original investigation.

Hence, it seems to the writer that we should be perfectly justified in insisting that every thesis undertaken by a student shall contain an element of investigation, and that by so doing we are not only teaching him how to carry on research, a matter of the greatest importance for his professional success, but that we are also helping him to look at all his work through a man's, and not a boy's eyes; this matter being furthered by constant consultation with his teacher. If any exceptions were to be allowed to this rule, they should be very rare, indeed, and we ought to be very sure that the student's professional and scientific education will be decidedly advanced by work upon the subject chosen, and that it will be conducive to his professional success in the long run, and not merely serve to drill him to perform a little better the duties of assistant in such engineering work as is liable to fall to his lot just after his graduation. Indeed, no greater mistake can be made in the engineering education of a young man that to sacrifice a thorough grounding in the scientific principles that underlie his profession for the sake of such a drill.

It is so seldom that a thesis which forms one of the exceptions referred to ought to be allowed, that no further reference will here be made to them; the remainder of the paper will be devoted to such theses as do involve original investigation. Probably the two largest classes of theses of this kind are: first, those involving experimental work; and second, designs. The number of subjects of the first class that can be chosen is enormous, as there are so very many matters in engineering that badly need experimental investigation. The only difficulties that can arise about adopting any subject which it it is desirable to investigate are the questions whether the time at the disposal of the student will admit of his making any substantial progress in the investigation of the subject proposed, and whether the facilities are available to do good and thorough work.

The investigation may be of such a character that it can be made by means of apparatus already existing in, or that can be constructed for, the laboratory, or it may require facilities that can only be had outside of the laboratory, as for instance, when a series of tests is made of some large engine, as an engine of some steamer, or that of some industrial establishment. In either case the thesis is entirely under the control of the professor in charge, and he ought of course to insist upon careful and thorough work, and to exercise the supervision necessary to secure it.

In the second case, however, a careful and thorough performance of the work often requires that certain privileges should be granted by the owners of the plant, as the work is very liable to interfere more or less seriously with the profitable work of the plant for the time being, or with the convenience of the owners. In such cases the student should not be allowed to undertake the subject unless a perfectly clear understanding is first had with the owners, and it is certain that all the privileges will be unhesitatingly granted which are needed in order that the work may be properly done. As a rule these privileges can only be secured if the owners are interested in the work, and consider that their own immediate advantage will be subserved by knowing the results. Hence it is that there is almost always more or less difficulty about performing this kind of thesis work outside of the laboratory, and it is therefore very important that the laboratory should be equipped as fully as possible with apparatus of such a character as to permit of the investigation of live engineering questions.

As to the various kinds of experimental investigations that can be taken up, those that continually press upon us for solution are so numerous that it seems hardly necessary to attempt any enumeration of them. In questions of the strength of materials alone, there is an enormous amount of investigation that should be made. We need more light (which can only be derived from experiment) upon the strength of iron or steel columns; the strength of riveted joints either for a tensile, or a transverse load; the strength of timber in various forms; the strength of fly wheels, etc., etc., including a list far too long to make any attempt at enumerating them. The steam engine furnishes an enormous series of questions which need investigation, besides a host of questions in regard to the behavior of steam under different circumstances. Then, besides problems involving the strength of materials and steam, there are a great many other matters that need to be investigated experimentally: as, rope transmission; belt transmission; efficiency of different machines, as of pulley blocks, of jackscrews, etc., etc. Such problems as the above arise in general engineering work, but in mining engineering, in electrical engineering, and in chemical engineering, etc., we have a host of other questions demanding investigation by means of experiment.

Let us consider next theses of the second class, viz: Designs. If it is proposed that, for thesis work, the student shall make a design, whether it ought to be allowed or not depends upon what kind of a design it is. If it is one which does not demand investigation on the part of the student, but merely requires him to follow precedent, and to go through the mechanical work of making certain usual cut-and-dried calculations, besides making certain drawings, then the subject is not one that will develop the powers of the student for investigation, and it ought not to be allowed. If, on the other hand, the design is so extensive that the student cannot work out all the details, then again the design ought not to be allowed. His work would not be thorough, as he would attend to the generalities and neglect the details. Thoroughness is one of the most important principles underlying any original investigation, and this should be impressed on the mind of the student.

On the other hand, designs should be allowed which do develop the student's powers of investigation, where he is called upon to make a careful investigation to determine the conditions which his design must fulfill, and to make further investigations to design it so that it shall fulfill all these conditions; where he calculates the dimensions of all the parts so that they shall have the requisite strength and stiffness, and does not rest content to determine them by some empirical rule or with no better reason than custom.

Often a thesis involves both experimental work and design, as for instance, when an experimental investigation requires a considerable amount of design to devise the machinery with which to conduct the experiments, or when, in order to make the design, it becomes necessary to perform certain experiments in order to obtain data from which to design the whole or certain portions.

There are other investigations suitable for theses which do not involve experimental work, and cannot be classed as designs, but no attempt to enumerate or classify them will be made here. In the opinion of the writer, the principles here laid down will apply to all, viz: that only such subjects should be allowed as will serve a purpose in the professional instruction of the student, and that, if the thesis is to accomplish this object in the proper manner, it should involve original investigation. It should also be noted that the introduction of laboratories into engineering schools has very much facilitated an adherence to these principles.

Now let us consider a little more in detail the process by which the thesis is evolved. First comes the choice of a subject. In some schools subjects are assigned, and in others the student is expected to take the initiative in proposing one. The writer prefers the latter method. Now, suppose the student is informed that he must write a thesis, that this thesis should involve investigation, and that a subject must be determined upon by a certain time, which shall meet the approval of the professor. With all such general informatien as the teacher can give, the student has at best a rather vague idea of what a thesis should be, and when he proposes his first list of subjects, it is an even chance whether there will be one of them suitable to adopt or whether all will have to be rejected as unsuitable, and some suggestions made of other subjects from which to chose. When the subject has once been chosen the teacher has to give the student some hints and directions, as to how to find the literature of his subject, and also as to what are the really most important questions for him to investigate at first in regard to it. Then the teacher sends the student off to look up the literature, and to think over and propose some plan of action. We will assume now that it is an experimental investigation that the student has before him. When he comes next and reports the results of his reading, and proposes his general plan, the teacher criticises it approving or disapproving according to circumstances, and suggesting further steps to be taken.

A course of a similar nature should be followed in the case of a design, or of any other thesis involving investigation, which, as has been said, all theses should involve. It will be plain that such a method of procedure is just what is needed to have the proper effect on the progress of the student, and it is also the course needed to secure thorough and reliable work on the theses.

By this method, however, it is plain that almost always the greater part of the ideas proceed from the teacher, although he tries to make the student originate all he can; and this is as it should be, and it is this fact that enables the schools to accomplish valuable work in connection with the theses, while accomplishing the best possible results as regards the instruction of the students.

The thesis is, therefore, really executed by the teacher and the student together, and the teacher's part in it is almost always the greater. None of the thesis work of any school should be published, therefore, unless the teacher believes in its value and correctness sufficiently to publish it with his own name attached, as that is a guaranty of its being done with such thoroughness as he is willing to endorse.

Any thesis work to which the teacher does not attach his name, if published, comes to us as the work of raw and inexperienced hands, and hence we have no surety that we can rely upon the results of the work. Hence the rule is an all important one in the case of any school that wishes to maintain the reputation of doing reliable work, that the theses are the property of the school, and that the student has no ownership in his thesis, and hence has no more right to publish it himself than he has to appropriate to himself another man's property.

If this rule is strictly adhered to, as it should be, the reliability of the published thesis work of our schools is tantamount with the reliability of the work of the teacher who took part in it and published it. Of course it is right and proper that the teacher in publishing should mention the student or students who wrote the thesis, either by stating what they did in the body of the paper, or, better, by coupling their names with his own in the authorship. Sometimes it may be desirable to have the paper rewritten, to render the wording, language and emphasis suitable for publication.

DISCUSSION.

Professor J. B. Johnson wished to say that this paper offered one of the best evidences they could have of the necessity for and benefit likely to come from an organization of teachers such as had been effected that morning. In this organization just such papers could be prepared and read and they would lead to very profitable results. He felt himself greatly benefited by listening to this paper.

PROFESSOR WM. S. ALDRICH had been greatly interested in listening to this paper. It seemed to him that subjects for a thesis divided themselves naturally into those which require some work of investigation and those which do not, and that the growing tendency is to adopt those subjects for theses which require some investigation. The review of some process or the historical developments of some branch of engineering is falling into disuse not because it is a survival of the ancient academic thesis, which is often claimed, but it is not the place for literary finish. He believed the tendency of the times is more toward original work in the graduating theses of students, the feeling being that the purely literary work should have been done earlier, and that we should discourage any lengthy review of a literary character. Outside of that, however, there are very interesting and valuable topics for theses which require no laboratory or shopwork, such as mathematical investigations—which are always in order and always in place, graphical work, geometrical work, and hundreds of others. It seemed to him that these were always in order, and could be classed as mathematical topics. Aside from these are subjects of design. The true design, it seemed to him, is a very good indication of the student's engineering ability up to a certain point. Of course it calls for a certain amount of ability and is simply one way of expressing that ability, but it seemed to him that the thesis design should be worked out in the shop and should not stop on paper. After the drawings are blue-printed, and all the students who have been interested have had copies of it, the student himself should go into the shop.

Furthermore, he thought it should more and more be insisted on that the student should limit himself entirely to an all-round treatment of one particular subject and not try to gaasp the whole field as he is very apt to try to do. The idea of getting all around a subject is a very good one for the student to realize before he leaves college, for sooner or later it comes up before him as a very important feature. As he cannot do everything in this world, cannot investigate everything, he should realize the wisdom of getting down to one particular line and one particular branch of that line of work. It seemed to him that the closing months of a technical course of study is a very fitting time in which to impress the student with these facts. He can only give a limited amount of time to his thesis work unless it is carried over into vacation, after engaging in practical work. That had been permitted in certain cases. A student may become connected with a certain firm where he can carry on his investigation while doing his other work and so complete his thesis after graduation. He closed by strongly indorsing the views expressed in the paper.

Professor Ricketts thought that the title of the paper more properly should have been Graduading Theses for Mechanical Engineers. He agreed with him of course in his ideas of the general value of laboratory work, but in confining theses in the civil engineering course to those involving original investigations in a laboratory, he would take direct issue with him. He quoted from Prof. Swain's paper to the effect that after a man learned how to make a certain test, there was no advantage in his making a thousand tests. That was the tendency to a certain extent in the theses in which laboratory work is necessary. On the contrary, for the civil engineer—and he was refering to civil engineering schools only—he did not believe a young man could do better than to take a design of a system of water works for instance, or of a bridge, and carefully work it out himself or under the instruction of his professor. They should, however, be forced to do the work for themselves as much as possible. What we should try to do is to give a man a good all-round engineering education. Although he is not expected to immediately design work himself, he would then be prepared to do so in the course of a comparatively short time. Now that could be done. He knew of a school in which prizes were given for the best thesis. The theses are submitted to engineers of national reputation, and after examination of them, although they involved no laboratory work whatever, but were mostly designs of engineering structures, the judges had reported that they showed a high order of merit and careful training. In one case they had reported that the young man who wrote it would be capable of reporting on any water supply. This illustrated his point. He did not believe it was necessary for a man to take for the subject of his graduating thesis something which involved shop work pure and simple. It might be absolutely necessary for a mechanical engineer, although he did not believe it, but he knew it was not necessary for the civil engineer. He doubted very much whether it was advisable to confine mechanical students to that class of work, once more referring to the remark of Prof. Swain as a reason for that opinion.

Professor Lanza said that he thought he had made his position plain in the paper. Both the speakers seemed to have assumed that he felt that the word investigation always invoved laboratory work. He did not believe he had made any such statement, and he did not wish to be understood that way.

Professor DeVolson Wood said this was a subject which had been under consideration in some degree in the Stevens Institute. He supposed they felt like most other institutions, free to do as they pleased, not trammelled by precedents, not following old courses and old systems and old methods because they are such, and from time to time the question of graduating theses had been raised. It had been argued by those who wished to do away with them entirely, that they seemed to be a waste of time; that young men could not be expected to do finished work; that they spent a great deal of time in hunting about to get a subject, and that was a waste of time; that something could be substituted that would be much better, for instance, a course of lectures, or divide the classes up into small sections and arrange work for those sections especially for their benefit. He would not undertake to bring forward all the arguments made on that side. On the other side it did not seem to be necessary to argue much, for when the question was put to the alumni—and it was before them that the discussion was made—the majority was so very large in favor of the thesis that argument was unnecessary. He had tried to keep watch of the subject and to see if some plan or some more satisfactory system of arranging the last term's work could be made. But instead of the thesis practice weakening, it seemed to grow stronger. In the Stevens Institute they gave to the senior class from about the first of April until the first of June, and extended that if necessary to the middle of June, to write, and report, and pass an examination upon a thesis. They were left largely free to choose the subjects. Perhaps one reason why, with many of the professors, the thesis held as strongly as it did, was due to the fact that they were selfish. Many professors from time to time have subjects which they would like to have investigated, and by making these subjects known to the students they are taken from time to time, and in such cases they report in connection with the professor. They were not bound in that case as to whether they would assist them or not, or whether they would compel them to abandon or to take subjects, though he thought they would exclude those which were thought to be too heavy for them to undertake in the time allotted. It was not wise to take a subject that required several years to properly investigate and spend only a few weeks upon it. They tried to avoid that. If the young men who undertake these subjects desire time beyond the regular term time, they, of course, were permitted to have it. If they showed diligence in the work upon their subjects up to the time of commencement, they were allowed to graduate the same as if they had completed their subjects, with the understanding that they were to complete them. In a few cases they had made valuable investigations, requiring weeks beyond commencement day. The character and scope of the subjects covered a wide field. Some subjects require investigation in the laboratory, some require investigation in the library, some require a great deal of mathematical work. He had had a great deal of work done in that particular line, but they had not formulated the matter as definitely, perhaps, as was advisable, as to what subjects were admissible. But the one thing which some one had already mentioned was certainly of importance, and that was that the young man should take one subject and work at and around, and upon, and under and through that one subject. That one feature was certainly important, but, aside from that, even an occasional review, a review in civil engineering and in many cases in mechanical engineering, might be made exceedingly valuable. It was not necessary that there should be laboratory work in order to make a commendable thesis.

Professor Lanza in closing said that he did not know that he had anything to say, except that he did not intend to convey the idea that investigation in the laboratory was invariably necessary. He did say, however, that the student should carry on investigation, whether in the laboratory or in literature or otherwise, and that applied to any kind of an engineer.

PROCEEDINGS

OF THE

CLOSING GENERAL SESSION

OF THE

ENGINEERING CONGRESS.

CLOSING SESSION.

SATURDAY, AUGUST 5, AT 10 O'CLOCK A. M.

The formal closing session of the Congress of Engineering Societies was called to order in the Hall of Washington at 10 A. M. on Saturday, August 5, 1893, by Mr. Chanute, first vice-chaïrman of the general committee.

Mr. Chanute made a brief opening address in which he stated that an enormous amount of professional work of the best kind had been done since the opening session on July 31st, and that he would call up successively the chairmen, or secretaries, of the seven divisions of the Congress, who would give brief accounts of the nature and amount of work accomplished in their respective divisions.

The first speaker called upon was Mr. William Metcalf, Chairman of Division A, on Civil Engineering who made the following report:

Six sessions of this division had been held and the work accomplished can perhaps best be shown by the following general statement:

Sixty-three papers in all were presented. Of these fifty had been printed and distributed for discussion and covered about twelve hundred pages of printed matter, with numerous plates and cuts. The papers not printed were received too late to be properly prepared and put in type.

The subjects treated may be classified under the following heads: Common Roads; Railways—Terminal system, Signalling, Locomotives, etc.; Cable Railways; Bridges—Substructure and Superstructure; Canals; Foundations; Surveys and Surveying Instruments; Metals—Their Treatment for Structural Purposes; Grain Elevators; Paving Brick; Carbon—Its Uses in Electrical Engineering; Electric Light Plants; Hoisting Machinery; Inland Transportation; Navigation Works; Improvement of Rivers; Improvement of Harbors; The Plant of Commercial Ports; The Laying-out of Cities; Water Works; Sewers and Sewerage; Tunnels; and the Testing of Building Materials. Twelve countries are represented in the authorship of these papers as follows: Germany 20, Mexico 6, Portugal 5, England 3, Holland 2, France 2, South Amercia 2. Canada 2, Italy 1, Nova Scotia 1, Australia 1, United States 18, making a total of 63. The work of translation of these papers presented in foreign languages had been done, in every instance, by volunteers from the membership of the society, by members thoroughly conversant with the subject under consideration.

The interest manifested in the papers presented is evidenced by the fact that three hundred and eighteen engineers registered in this division during the sessions, and the average attendance at each session was about one hundred and twenty-five. The discussions had taken a wide range and on account of the limited time had been entirely confined to those presented orally. Many interesting and valuable written discussions were received which it had been impossible to present at the sessions, but which would be published in connection with the papers. The number of valuable additions to the literature on the subjects mentioned was so great that it was impossible in this summary to do them all justice, and it was thought best not to attempt it. It might, however, be asserted that the results of the sessions of this division of the Congress would be far reaching and productive of great benefit to the profession of Civil Engineering all over the world.

Mr. E. B. Coxe, chairman of Division B, Mechanical Engineering, next made a report for that Division, stating that he could only echo what his colleague, Mr. Metcalf, had said, as to the interest taken in the papers. The speaker said that the thing which impressed itself upon him most strongly at these meetings was the tendency of modern engineering to learn and to state exact facts. No designer who has to place his machinery in competition in the market of any civilized country can any longer neglect the thorough professional study of every question and every detail that comes into play in the construction or use of such machines. He also advocated an international system of tests.

Mr. Chanute then stated that Divisions C and D, Mining Engineering and Metallurgical Engineering, would be reported on jointly.

The report was made by Dr. Raymond, Secretary of the American Institute of Mining Engineers, who stated that something like twelve hundred pages of printed papers had been placed before their members, who had discussed the same with a great deal of interest and had accomplished useful results. The attendance had averaged about one hundred and twenty-five or one hundred and thirty. Both the theoretical investigator and the practical engineer were fully represented at the sessions. On the side of mining there had been representations of the best modern methods of mining as practiced here and abroad. Several modern machines had been described and discussed, particularly the latest achievements in applications of electricity. The speaker closed by expressing, on behalf of all divisions, their hearty recognition of the admirable services of the Committee of Arrangements and said that for the remarkable success of the Congress "We may render thanks to Heaven and thanks to them."

Mr. C. Frank Allen, Secretary of Division E, Engineering Education, then made a report for that division, giving a brief summary of the several papers, stating that a great deal of useful work had been accomplished by this division, and that a permanent society had been organized by the members of that division for the promotion of Engineering education.

The report from Division F, Military Engineering, was made by the chairman of the division, Major Clifton Comly, U. S. A., who stated that their sessions had been fairly well attended and had proved very interesting and advantageous. The subject of military engineering had been considered in its broadest sense and the thirty-seven papers presented covered a wide field. While principally contributed from officers in the United States service, yet many papers of great interest had been furnished by foreign officers.

Commodore George W. Melville, chief engineer U. S. N., then made the following report from Division G, Marine and Naval Engineering and Naval Architecture: "Mr. Chairman, it is very gratifying to me to be able to report to the Congress that the meetings of the division of marine and naval engineering and naval architecture have been eminently successful in the number and character of the papers read as well as the attendance and the discussion. The average attendance has been about seventy, and the discussion of the papers has developed many points of great value to the profession and to the marine interests of this and other countries. The most eminent naval architects and marine engineers of Great Britain, the continent of Europe and this country, by the free interchange of their ideas and the results of their great experience, have made the record of this division of the Congress of great value, and it gives me great pleasure to find my own opinion endorsed by the remark of one of England's foremost naval architects, 'that the published proceedings of this division would form one of the most valuable collections of information for naval architects and marine engineers that has ever been published.' While I can hardly say that any novelties were developed at our meetings, the free interchange of opinion by so many eminent members of the profession cleared up some points on which there was doubt, and has put our information in very satisfactory shape.

The interchange of ideas among the engineers and naval architects of the Great Lakes and our western rivers with those from the countries bordering on the Atlantic and Pacific has been productive of mutual benefit. Each had something to learn from the other, and this Congress has furnished the opportunity."

The speaker then expressed the sense of obligation felt by the members of that division to J. Wiley & Sons, for assuming the cost of publishing their proceedings, and to the committee in charge of the Congress.

The chairman then introduced the Baron Guinette de Rochemont, who made an address in French and offered a resolution, which was translated by Mr. Chanute, the resolution being as follows: "Resolved: That a uniform system of testing material is desirable for purposes of exact comparison." The foregoing resolution was put to vote and unanimously adopted.

The chairman then stated that he would now call for remarks from representatives of foreign nations who had honored these deliberations with their presence, and that he would first ask Professor Unwin of Great Britain to respond in behalf of his country.

Professor Unwin said in substance:

That all were glad to recognize engineering as a scientific profession, constantly gaining in dignity and importance; that he could not help remarking that this was the first engineering meeting within his recollection at which there had been a recognition of engineering education as being an important subject;

that not only had it been recognized, but given a place equal in importance to the great branches of engineering; that the United States was in a favorable position in this respect, having, through the munificence and public spirit of its citizens, had magnificant endowments for engineering education, so that it was solving a most interesting problem by taking an entirely new step in the work laid out for the engineer in recognizing the necessity for a foundation of scientific education for engineers.

After referring to the kindness with which he had been received, the speaker concluded as follows: "Those of us who have been here will go back to Europe with the impression that we have an immense deal to learn from you American engineers. Gentlemen, American enginering is not unknown to us, we read the transactions of your societies, we hear of the immense works which in your country the engineer is called on to carry out, we acknowledge that you have earned from us the tribute of a most sincere respect."

The chairman next introduced Mr. A. Flamant, of France, who spoke in French, his remarks being translated by Mr. Chanute.

Mr. Flamant said that he felt it a great honor to be called upon to speak before so numerous an assembly of distinguished engineers and regretted profoundly that he must do so in his mother tongue; that the French delegation had been impressed with the vast deal which it might learn by studying the works and the ideas of the great nation which is astonishing other countries, both by the rapidity of its development and by the originality and the boldness with which its engineers are solving the most varied problems and, unhampered by tradition, facing and conquering difficulties which formerly seemed insurmountable. He mentioned that among the numerous subjects which had been discussed in the Congress he had been more particularly interested in the progress which had been made in sanitary engineering in the United States, resulting in diminution of disease and in increase of the average term of life. He said he was also impressed with the discussions which had taken place concerning the testing of materials of construction. This was a question which had attracted the attention of the French Government, and he was glad that a resolution had been passed to promote a uniform system of testing materials, as this must result in international action upon this important subject, and he regarded it as one of the most important benefits which the industry of the world would receive from the Engineering Congress of Chicago.

The next speaker was Professor Hartmann, of Germany, who, as representative of the German Engineering Society (the Verein Deutscher Ingenieure) extended the most cordial greetings of the members of his society to the American engineers, and then spoke of the magnificence of the Columbian Exposition, and of the rapidity with which it was constructed, and said that it was only due to the labors of the engineers that all the works connected therewith could have been accomplished in so short a space of time.

The chairman next called upon Professor Francis Reuleaux, who, after alluding to the great work accomplished at the Exposition, also spoke of the wonderful advance which had taken place in the United States in the designing and construction of machinery. He said that the point that struck him most forcibly was the method of precise measuring which had been developed to such an astonishing degree, ordinary workmen measuring to thusandths of an inch. This accuracy gave them a great advantage over the workingmen of other countries who did not work in that way. Germany and France were beginning to follow the example, but American engineers were the leaders.

Col. Nabor Soliani, engineer of the Italian Navy, was next introduced, and said that the Italian delegation had come prepared to learn and to see great things, but that its expectations had already been surpassed, and that it would go home with a larger stock of knowledge and of useful information than it had expected to bring back; that he considered the work done by the Engineering Congress to be of unusual importance, and that it had been a most agreeable feature that he had had the opportunity of making the acquaintance of so many distinguished engineers of the United States and he begged them all to accept the expression of his gratitude and best thanks.

The Chairman next called upon Chev. Celso Capacci of Italy, who said that the importance of the different questions treated in this Congress, the number and the high value of the papers presented as well as the discussion which followed, have made of this one of the most important and remarkable engineering congresses which had yet been held and that in connection with the wonders of the Columbian Exposition the occasion had been a most memorable one.

The next speaker was Nicolas Vosnessensky of Russia, who said that no country in the world presented so much interest for Russian engineers as the United States of America, because in no other countries, except the United States and Russia, were there such immense distances for transportation by rail, or such great rivers and lakes for inland navigation, and he was much impressed by the great development of such natural conditions by the skill of the American engineers. He esteemed it a privilege to have been present at the discussions concerning new great engineering problems, such as the construction of a new deep water communication between Lake Ontario and the Atlantic, and the construction of a new canal from Chicago to the Mississippi river, and the construction of the Nicaragua Canal. Before returning to Russia, he desired, as the representative of the civil engineers of Russia, to express his most hearty thanks for the kindness with which he had been received, and to wish the American engineers the most complete success in all their further engineering enterprises.

Mr. Feliks Rycerski of Russia said that he had been much impressed with the simplicity and practicability of all American engineering works which he had seen.

Prof. W. Ritter, of Switzerland, said that, coming from a country in which there exists so many engineering works as in Switzerland, he had been specially surprised with the admirable ability with which the American engineers adapted their constructions to the various circumstances pertaining to each case, with their energy in overcoming the greatest obstacles, and with the great importance which they attached to engineering education, and last, but not least, with the courtesy and amiability with which they had received their foreign guests during this Congress.

Alfred Vander Stegen, of Belgium, said that he had found in the United States many noticeable improvements in the construction of machinery, such as the system of interchangeable parts, which was certainly the best way of joining cheapness to perfection and accuracy, he also spoke of the various automatic attachments adopted everywhere, but especially in the rolling mills. He said that in European countries much had still to be done in that direction, and that it was one of the admirable results of this engineering congress that the representatives of all nations met together to interchange their knowledge and experience, so as to advance science and general progress. He said that an exposition was to take place next year in Antwerp, and, perhaps, also an engineering congress; that while these would be far less important than the present occasion, he yet hoped that some of the American engineers would visit Belgium in 1894 and give an opportunity for a return of the courtesies which the foreign engineers had received in Chicago.

The last address was made by Mr. T. Bergendal of Sweden, who said that among the many things which had astonished the numerous experts (from Sweden) on the manufacturing of steel and iron, was the rapid progress which had been made in the United States in the production of iron smelted with charcoal, which production had already reached the same quantity as the output of Sweden: that it was gratifying to trace, among the methods by which this had been accomplished, reminiscences from the old country in the form and shape of the furnace shaft, this being the same as the form finally adopted in Sweden after several hundred years of experience. He also expressed his gratitude to American engineers for their courtesy and facilities extended for visiting their works.

The Chairman, after calling for representatives from various other countries who did not respond, thanked all of those present in the name of the engineers of Chicago, for having selected this city for this great unique gathering, from which he hoped the best results would follow, and which he also hoped to see repeated at some opportune time. He then declared the session closed and the congress adjourned.

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